RESTRICTED

SUMMARY TECHNICAL REPORT
OF THE
NATIONAL DEFENSE RESEARCH COMMITTEE

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SUMMARY TECHNICAL REPORT OF DIVISION 7, NDRC

VOLUME 2

RANGE FINDERS AND TRACKING

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT
VANNEVAR BUSH, DIRECTOR

NATIONAL DEFENSE RESEARCH COMMITTEE
JAMES B. CONANT, CHAIRMAN

DIVISION 7
HAROLD L. HAZEN, CHIEF

WASHINGTON, D. C., 1947

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NOTES ON THE ORGANIZATION OF NDRC

The duties of the National Defense Research Committee were (1) to recommend to the Director of OSRD suitable projects and research programs on the instrumentalities of warfare, together with contract facilities for carrying out these projects and programs, and (2) to administer technical and scientific work of the contracts. More specifically, NDRC functioned by initiating research projects on requests from the Army or the Navy, or on requests from an allied government transmitted through the Liaison Office of OSRD, or on its own considered initiative as a result of the experience of its members. Proposals prepared by the Division, Panel, or Committee for research contracts for performance of the work involved in such projects were first reviewed by NDRC, and if approved, recommended to the Director of OSRD. Upon approval of a proposal by the Director, a contract permitting maximum flexibility of scientific effort was arranged. The business aspects of the contract, including such matters as materials, clearances, vouchers, patents, priorities, legal matters, and administration of patent matters were handled by the Executive Secretary of OSRD.

Originally NDRC administered its work through five divisions, each headed by one of the NDRC members. These were:

Division A — Armor and Ordnance
Division B — Bombs, Fuels, Gases, & Chemical Problems
Division C — Communication and Transportation
Division D — Detection, Controls, and Instruments
Division E — Patents and Inventions

In a reorganization in the fall of 1942, twenty-three administrative divisions, panels, or committees were created, each with a chief selected on the basis of his outstanding work in the particular field. The NDRC members then became a reviewing and advisory group to the Director of OSRD. The final organization was as follows:

Division 1 — Ballistic Research
Division 2 — Effects of Impact and Explosion
Division 3 — Rocket Ordnance
Division 4 — Ordnance Accessories
Division 5 — New Missiles
Division 6 — Sub-Surface Warfare
Division 7 — Fire Control
Division 8 — Explosives
Division 9 — Chemistry
Division 10 — Absorbents and Aerosols
Division 11 — Chemical Engineering
Division 12 — Transportation
Division 13 — Electrical Communication
Division 14 — Radar
Division 15 — Radio Coordination
Division 16 — Optics and Camouflage
Division 17 — Physics
Division 18 — War Metallurgy
Division 19 — Miscellaneous
Applied Mathematics Panel
Applied Psychology Panel
Committee on Propagation
Tropical Deterioration Administrative Committee

NDRC FOREWORD

As events of the years preceding 1940 revealed more and more clearly the seriousness of the world situation, many scientists in this country came to realize the need for organizing scientific research for service in a national emergency. Recommendations which they made to the White House were given careful and sympathetic attention, and as a result the National Defense Research Committee [NDRC] was formed by Executive Order of the President in the summer of 1940. The members of NDRC, appointed by the President, were instructed to supplement the work of the Army and Navy in the development of the instrumentalities of war. A year later, upon the establishment of the Office of Scientific Research and Development [OSRD], NDRC became one of its units.

The Summary Technical Report of NDRC is a conscientious effort on the part of NDRC to summarize and evaluate its work and to present it in a useful and permanent form. It comprises some seventy volumes broken into groups corresponding to the NDRC Divisions, Panels, and Committees.

The Summary Technical Report of each Division, Panel, or Committee is an integral survey of the work of that group. The first volume of each group's report contains a summary of the report, stating the problems presented and the philosophy of attacking them, and summarizing the results of the research, development, and training activities undertaken. Some volumes may be "state of the art" treatises covering subjects to which various research groups have contributed information. Others may contain descriptions of devices developed in the laboratories. A master index of all these divisional panel, and committee reports which together constitute the Summary Technical Report of NDRC is contained in a separate volume, which also includes the index of a microfilm record of pertinent technical laboratory reports and reference material.

Some of the NDRC-sponsored researches which had been declassified by the end of 1945 were of sufficient popular interest that it was found desirable to report them in the form of monographs, such as the series on radar by Division 14 and the monograph on sampling inspection by the Applied Mathematics Panel. Since the material treated in them is not duplicated in the Summary Technical Report of NDRC, the monographs are an important part of the story of these aspects of NDRC research.

In contrast to the information on radar, which is of widespread interest and much of which is released to the public, the research on subsurface warfare is largely classified and is of general interest to a more restricted group. As a consequence, the report of Division 6 is found almost entirely in its Summary Technical Report, which runs to over twenty volumes. The extent of the work of a Division cannot therefore be judged solely by the number of volumes devoted to it in the Summary Technical Report of NDRC: account must be taken of the monographs and available reports published elsewhere.

The Fire Control Division, initially Section D2 under the leadership of Warren Weaver and later Division 7 under Harold L. Hazen, made significant contributions to an already highly developed art. It marked the entrance of the civilian scientist into what had hitherto been regarded as a military specialty.

It was one of the tasks of the Division to explore and solve the intricate problems of control of fire against the modern military aircraft. Gunnery against high speed aircraft involves fire control in three dimensions. The need for lightning action and superlatively accurate results makes mere human skills hopelessly inadequate. The Division's answer was the development of the electronic M-9 director which, controlling the fire of the Army's heavy AA guns, proved its worth in the defense of the Anzio Beachhead and in the protection of London and Antwerp against the Nazi V-weapons. In addition to producing mechanisms such as the M-9, the Division made less tangible but equally significant contributions through the application of research methods which had a profound, even revolutionary, influence on fire control theory and practice.

The results of the work of Division 7, formerly Section D2, are told in its Summary Technical Report, which has been prepared at the direction of the Division Chief and has been authorized by him for publication. It is a record of creativeness and devotion on the part of men to whom their country will always be grateful.

J. B. Conant, Chairman
National Defense Research Committee

Vannevar Bush, Director
Office of Scientific Research and Development

[redacted]

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FOREWORD

IMMEDIATELY UPON its formation, the Fire Control Division (initially Section D-2, later Division 7) of NDRC focused its attention upon antiaircraft artillery as the most difficult and tactically the most important problem in fire control. Investigation soon confirmed the optical range finder as the greatest individual instrumental contributor to inaccuracy of AA fire. Intensive work was initiated by the Division to strengthen this weakest link, and it grew into a large, diverse and comprehensive series of investigations. Physiological and psychological characteristics of range finder operators rapidly emerged as factors of the greatest importance and indicated that attention must be paid to the man-instrument combination. At this point the author of this volume, Dr. Samuel Weiller Fernberger, professor of psychology at the University of Pennsylvania with a notable record in the field of psychophysical measurement methods, was called to the Division to guide the psychophysical aspects of this work as the associate of Dr. T. C. Fry, the member of the Division who carried responsibility for the entire optical range finder program of the Division.

A great volume and range of work was done in this field under many auspices including the Fire Control Division. A substantial fraction of this work has continuing importance as is evident to even the casual peruser of this volume. It was not until near the end of the war that radar data-gathering methods had sufficiently demonstrated their superiority of performance and their dependability (including immunity to enemy countermeasures) to preclude the possibility that optical methods might suddenly assume critical importance. Consequently intensive work on all aspects of the optical range finder program were still receiving substantial Service support as OSRD activities were transferred to the Services. The most enduring values, however, are probably the understanding and the extensive quantitative data now available on the design of instruments to fit human operators. In the guidance of such investigations the author has played a leading role.

Despite the current and probable future domination of radar, much of the work surveyed by this volume is of continuing interest provided it is accessible to the worker. It is believed that this volume, presenting an organized abstract of the extensive operator-instrument studies and all aspects of optical range finders, will enable the officer or investigator concerned with these areas to gain rapid access to pertinent material which might otherwise be submerged by the sheer quantity of material involved.

H. L. HAZEN,
Chief, Division 7

PREFACE

THIS MONOGRAPH is an attempt to describe the experimental work performed on the development of optical range finders and their operation during the war years, by the Fire Control Division of the National Defense Research Committee and by other agencies so far as is known by the author. The bibliography of more than 600 titles will indicate the enormous amount of work which has been completed on this topic. Most of these reports will be found in Service files.

Because of the large amount of material, no attempt is made in the present text to give complete description of any single experimental study. Rather the text should be used as a handbook to indicate to a newcomer at a Service desk what has been accomplished and in what sources he may find complete and adequate descriptions of individual experiments.

Early in the development of this Section of the Fire Control Division, it was realized that one must consider the man-instrument combination in order to obtain the best results in operation. Hence research was carried on to improve the optical ranging instruments themselves, to devise new and better instruments, to improve methods of operation and calibration under field conditions, and also to provide methods for selection of those Service personnel who would become the best operators, and to provide better and more economical methods for the training of these selected personnel. Hence certain chapters will deal almost exclusively with problems of physical optics, others with problems of physiological and psychological optics and still others with problems of psychological selection and training.

A more complete description of the history of this work, its objectives, and of the responsible personnel will be found in the Introduction, Chapter 1. Directly responsible for the direction of the work of the Section was Dr. Thornton C. Fry and later Mr. P. R. Bassett, who subsequently replaced Dr. Fry as Chief of the Section.

SAMUEL W. FERNBERGER

This volume, like the seventy others of the Summary Technical Report of NDRC, has been written, edited, and printed under great pressure. Inevitably there are errors which have slipped past Division readers and proofreaders. There may be errors of fact not known at time of printing. The author has not been able to follow through his writing to the final page proof.

Please report errors to:

JOINT RESEARCH AND DEVELOPMENT BOARD
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WASHINGTON 25, D. C.

A master errata sheet will be compiled from these reports and sent to recipients of the volume. Your help will make this book more useful to other readers and will be of great value in preparing any revisions.

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Note: OSRD appointees, project numbers, and contract numbers are listed at the end of Volume 1.

Chapter 1

INTRODUCTION

THIS TEXT is not intended to be an encyclopedia on ranging instruments or ranging techniques. It is an attempt to present, in orderly and systematic form, the developments known to Section 7.4, NDRC, of the war years 1940 to 1944 in the instrumental and operational fields for optical range finders and certain related subjects. Its purpose is to orient some Service individual who may want information regarding either the trends and developments over the entire field or in regard to some specific problem. The bibliography will indicate that there have been nearly 600 titles issued during this five-year period. (Numbers in parentheses in the text refer to items in the bibliography.) Most of these reports will be found in Service files. This text is merely a systematic arrangement of abstracts of these many titles and should act as a starting point to guide an individual to the pertinent original source or sources for his information. With changing personnel in Service Commands and in Service Offices, it is believed that much of this material will be lost and disregarded unless some such device as the present text is available for orientation.

The list of titles includes, it is believed, all reports which have been submitted to the Fire Control Division of the National Defense Research Committee bearing on these subjects. To these have been added pertinent titles issued by the Applied Psychology Panel, NDRC, and it is believed that this list is complete. Also will be found titles from various United States Service sources and from British sources, notably the Armament Research Laboratory [A.R.L.]. It is certain that titles from both these sources are not complete, but there are listed all items readily available to the writer.

Immediately after the formation of the National Defense Research Committee in 1940, the Fire Control Section under the chairmanship of Dr. Warren Weaver began a survey of the entire chain of events in the fire control system from the obtaining of the target position to the firing of the guns. At this time they decided that one of the principal sources of error was to be found in the optical range or height finders which were the standard ranging instruments available at that time. They also decided that the antiaircraft problem was not only that presenting the greatest complication due to extreme ranges and to angular rates of the targets but also this was a period in the war when improvement of antiaircraft fire was essential because of German air superiority at that time. A theoretical estimate of the effect of range finder accuracy on battery performance will be found in a Frankford Arsenal Princeton Branch report. (229) Hence, it was the belief of this Section that, if the antiaircraft optical range finder problem could be solved, one could apply these results to other and simpler situations.

Dr. Thornton C. Fry was placed in charge of the work with optical range finders. Subsequently Dr. Harold L. Hazen became Chief of the Fire Control Division, and later, upon the withdrawal of Dr. Fry from Division membership, P. R. Bassett became Chief of the Section in which the range finder activities were lodged. The NDRC Fire Control Division came to a third important decision—namely, that one could not consider a range finder instrument in isolation but that, to obtain a real insight into the situation one must consider the combination of the instrument and its operating personnel in combination. This realization of the importance of the man-instrument combination very greatly influenced the pattern of subsequent research initiated by this Section of NDRC.

As a result of this survey and of these decisions, the Fire Control Division set up an organized program of research to attempt to determine how the optical rangefinding instruments could be improved, and how various sources of error could be recognized and eliminated or controlled, and how one could improve operating performance by selection of range-finder personnel and training them in the use of the instrument. To this end, two sorts of projects were initiated. Princeton University agreed to set up a laboratory at the Antiaircraft Center at Fort Monroe. Here work was done with actual instruments under field conditions, using as operating personnel Army Test Observers and students in the Antiaircraft Height Finder School. The second type of project was initiated at a number of universities and academic institutions where experiments were carried

out under more exactly controlled laboratory conditions. Such contracts were made with Brown, Dartmouth, Fatigue Laboratory at Harvard, Howe Laboratory of Ophthalmology, Ohio State, and Tufts. Here problems of various sorts primarily involving personnel and the use of range finders were continued for many months and some of these contracts are still in force and still producing fruitful results.

After some of the more important sources of error were discovered, contracts were made with various manufacturing firms for special devices and/or redesign of the instruments so that these errors could be eliminated or at least alleviated and controlled. Such contracts were made with the American Gas Association Testing Laboratories, Bausch and Lomb Optical Company, Eastman Kodak Company, Foxboro Company, and Keuffel and Esser Company. Toward the end of the program each of the three optical companies—who are the sole commercial producers of range finders in this country—began complete redesign of optical range finders on the basis of knowledge obtained during these several years of experimentation.

In 1942 it was announced that the Antiaircraft School would be moved from Fort Monroe to Camp Davis. Inasmuch as much of the work of the group had been completed, it was decided to close the contract with Princeton University under which the laboratory at Fort Monroe had been conducted. The Princeton group was immediately employed by the Frankford Arsenal, and became a Princeton Branch of that organization for continued research in fire control. This arrangement lasted until July 1944. Also in 1942 a National Research Council Committee on Service Personnel Selection and Training was organized with Dr. John M. Stalnaker, Chairman, and Dr. Charles W. Bray, Executive Secretary. The interests of this committee covered a much larger field than that of fire control. However, arrangements were made by the Fire Control Division of NDRC to transfer the problems of selection and training of range finder personnel to this new committee. They set up field laboratories for the Army at Camp Davis, N. C. and for the Navy at Fort Lauderdale, Florida and at the Advanced Fire Control School at Washington, D. C. Subsequently the work and personnel of the National Research Council Committee was taken over by the Applied Psychology Panel of NDRC when this was formed in 1943 under the chairmanship of Dr. Walter S. Hunter.

The Rangefinder Section of the Fire Control Division was fortunate, throughout its existence, in securing the cooperation of highly interested and excellently informed officers in both Services who aided with their advice and assisted in the direction of the research. At a very early stage this cooperation took the form of frequent—usually monthly—meetings of a small group at which the purposes and progress of the program were carefully examined. These meetings were so valuable that they were eventually given recognition by formal designation of the officers as members of a "Steering Committee" for the project. As officers were called away to distant assignments, others were named to replace them so that this small body—never greater than six at one time—continued to exist throughout the life of the study. The officers who thus cooperated were: from the Army, Colonel W. R. Gerhardt, Colonel G. W. Trichel, Colonel G. B. Welch, Lt. Col. A. L. Fuller, and Major R. S. Cranmer; from the Navy, Capt. M. E. Murphy, Capt. P. E. McDowell, and Comdr. S. S. Ballard. Except for the complete cooperation of this group, and of the Command of the Antiaircraft Heightfinder School, the field experiments at Fort Monroe would have been impossible, and the adequate interpretation of many of the laboratory studies would have been difficult.

The writer of this report, Samuel W. Fernberger, was associated with the project throughout, first as a consultant in the psychological factors involved, and after September 1941 by direct appointment as Technical Aide to the Fire Control Division.

In the following pages will be found the results of all of these experiments in a systematic and orderly presentation. Little attempt has been made in regard to a critical evaluation by the writer. Instead he has been content to let the findings of each experiment stand on its own merits but has attempted to integrate the various studies into a consistent picture. Frequently the report of any particular experiment has been expressed in the own words of the investigator. The reader is cautioned that he should consider the present text only as a book of reference and, if he desires detailed information, he should turn to the original reports of these various studies.

The reader may be assisted by an outline of the following text and an indication of the philosophy and logic underlying the particular structure adopted. This is particularly true because of the nature and widely varied problems treated in the many

references here considered. One will find studies on instrumental design, physical optics, physiological optics, anatomy, physiology, and psychology.

Following this introduction, in which are summarized the point of view and the subsequent content, is Chapter 2 in which are outlined certain fundamental studies which are basic to the entire rangefinding problem. In this are outlined several laboratory studies which determined the relative acuities which might be expected with different types of instruments and fields and also a quantitative analysis of the relative importance of the factors operative in stereoscopic vision. The third chapter outlines the comparative studies made with existing instrument types.

The next five chapters (Part I) deal with the existing range finder instruments themselves and indicate factors of construction and of errors—and of their correction—which are independent of the human operators. Hence Chapter 4 deals with perspective errors. It includes a general discussion; the use of end window stops to reduce this source of error and the question of the interocular setting to be placed in the instrument. The fifth chapter deals with temperature effects and considers such palliative methods for the elimination of such errors as air stirring versus charging the instrument with helium. An additional section deals with the development of thermally stable instrument parts. Chapter 6 outlines the work on base length and power, while Chapter 7 discusses the problem of the calibration of range finders. Finally, Chapter 8 deals with a group of miscellaneous instrumental and operational defects which do not naturally fall into any of the immediately preceding four chapters, such as pentaprism rotation, filters, leveling, and the like.

The next division, Part II, which comprises four chapters, has to do with the man-instrument combination, and involves a discussion of effects or possible effects of a supposedly adequate trained operator using a perfect instrument. Hence these chapters include a discussion of certain psycho-physiological factors in the operators and have to do largely with the operational aspects irrespective of inherent instrumental errors. Chapter 9 describes the various psycho-physiological factors of the operators. It includes such problems as fusional limits, fatigue, and motivation; the effect of lay-off, of loud sounds, of sex differences, and of the administration of drugs, changes of posture and the like. Chapter 10 outlines the experiments indicating the importance of the relative position of reticle and target images and hence of the importance of tracking, while Chapter 11 describes the work on the effects of haze and atmospheric scattering. A final short chapter (Chapter 12) discusses such miscellaneous human operational problems as continuous versus bracketing contact, the focusing of the eyepieces, the height of image adjustment, and the use of the range finder as a spotting instrument.

It will be remembered that the discussion in Part II assumes a perfect instrument and an adequate operator. The two chapters following (Part III) deal with the problem of obtaining such an adequate operator. The first of these, Chapter 13, outlines the research fundamental to obtaining the best Service personnel to be given training. This chapter on selection describes the work accomplished on each of the anatomical and physiological factors necessary for adequate performance on a range finder. In this connection considerable space is given to the successful search for a test of stereoscopic acuity which would validate with subsequent performance. Some space is also given to the development of simple tests of emotional stability. After the promising operator has been selected, he must be adequately trained. In Chapter 14 the problems of training are discussed. These include such problems as the assessment of performance during training, and the development of training methods and of training devices.

Up to this point in the text, the discussion has been concerned with existing range finder instruments, with their operation, and with the selection and training of their crews. The last three chapters (Part IV) deal with new developments in the art. Chapter 15 describes the development of certain short-base range finders and their application to ground and aerial targets. A short description is added, for the sake of completeness, of work on simultaneous stadiametric ranging and tracking. Chapter 16 deals with a thoroughgoing study of the design of reticles for stereoscopic range finders. In Chapter 17, finally, is very briefly outlined the development of certain new instruments whose design was initiated by NDRC and by other agencies.

At the end is a bibliography of the reports discussed in the text. Some few additional titles are included for the sake of completeness. Following each title is a number in parentheses which indicates the chapter or chapters in which reference to this

item is made.

It is assumed that the reader of this summary will have a fundamental knowledge of range finders and their operation, such as will be found in the Service manuals and in Donald H. Jacobs, *Fundamentals of Optical Engineering,* McGraw-Hill, 1943. In order to read critically many of the original reports here summarized, it will be necessary for the reader to have a knowledge of fundamental statistical procedures and the ability to interpret final statistical values, as well as, in many cases, a knowledge of fundamental physical or physiological optics or of experimental or personnel psychology. A readable outline of such statistical procedures which does not require too extensive a background of pure mathematics will be found in J. P. Guilford, *Fundamental Statistics in Psychology and Education,* McGraw-Hill, 1942. An outline of personnel procedures is by A. T. Poffenberger, *Principles of Applied Psychology,* Appleton-Century, 1942.

Chapter 2

SOME FUNDAMENTAL STUDIES

2.1 INTRODUCTION

A NUMBER of new optical arrangements have been suggested for the improvement of the acuity of range finding instruments. It would have been both expensive and time-consuming to have had each of these optical systems built into precision instruments and their relative accuracy determined by comparative field studies. Hence a controlled laboratory experiment was initiated at the California Institute of Technology [CIT] to give insight into this problem. This was accomplished by building eight different optical systems into a single laboratory instrument so that the experimenters could shift very rapidly from any one arrangement to any other.

2.2 REPORTS OF STUDIES

2.2.1 Description of Six Experimental Arrangements Tested

These tests are reported by CIT. (187) Six more or less untried arrangements were tested in conjunction with the two currently in use—namely, fixed reticle stereoscopic and simple coincidence with a divided field. The other optical arrangements were:

1. Simple full field coincidence.
2. Simple coincidence with red and green filters respectively in each image path, in the belief that color fringes might aid in increasing the accuracy of the setting.
3. Simple coincidence, but the images were flickered alternately. Thus when out of range one sees first the image on one side, and then on the other, with this cycle repeated regularly, about five times per second, or too slowly for retention of vision to take place. When nearly in range with this system, the target appears to oscillate slightly to left and right. Ranging correctly consists of obtaining a single stationary image.
4. Coincidence strips was another arrangement and this was similar to the usual divided field coincidence except that the field was divided into about 30 equal horizontal parts. These horizontal strips were sufficiently narrow to insure that ordinary targets will be cut by at least one dividing line, irrespective of the target's position in the field. This then eliminates the necessity of holding the target at a particular part of the field as is the case with the usual coincidence split field instrument. The strips alternately pass only the deviated or the undeviated ray, such that, when out of range, the target appears as if in several pieces, the number of these depending upon the vertical dimensions of the image as compared with the width of the strips. Ranging consists of removing the relative horizontal displacement of these parts so that the image is seen as a complete whole.
5. Ortho-pseudo is a double stereoscopic arrangement but without a fixed reticle. Two images of the target are seen, one displaced vertically by a fixed amount with respect to the other. A ray from either telescope enters into the formation of each of the images, and they are seen stereoscopically. When out of range, the images appear at different depths, since the deviated ray of one image falls in a different eye from that of the other. Ranging consists in obtaining the images in a single plane in depth. The CIT arrangement differed from that of the Mihalyi instrument in that the images were not inverted with respect to one another, and they were at a fixed vertical separation independent of position in the field.
6. The last optical arrangement was called stereo strips. In this the field was divided into about 30 horizontal strips as in the case of coincidence strips noted above. However, the target is seen stereoscopically so that, when not in range, the parts in adjacent strips are displaced in depth with respect to one another. Ranging consists of obtaining the parts of the target in a single plane. There is no fixed reticle in this arrangement and, as in the case of coincidence strips, ranging is possible in all parts of the field. This instrument is described in the text.

2.2.2 Limitations of Arrangements Tested

There follows a discussion of the limitations of the various arrangements. Theoretically, all of the coincidence arrangements and the fixed reticle stereoscopic are basically equal in sensitivity. The two ortho-pseudo arrangements, on the other hand, possess a certain theoretical advantage. Whereas for

the fixed reticle stereo, a unit of deviation by the ranging wedges produces a given difference in depth between the target and the reticles, the separation in depth of the images in the ortho-pseudo arrangements is just double this amount, since the deviated ray takes part in the image formation in both eyes.

Principles of Ranging

These investigators point out the following general principles in regard to optical ranging. The accuracy of ranging may depend markedly upon the size, shape, and attitude of the target. In antiaircraft work, the target is of irregular contour, the apparent size varied and changing with time. The attitude also varies with time. Since full theoretical accuracy can be realized only for vertical lines or edges, the divided field coincidence will suffer to the extent that the target fails to present a vertical edge of reasonable length at the dividing line. The same is true of the coincidence strip arrangement, but if the target is large, the observer will have a choice of dividing lines. For all the other coincidence arrangements, a vertical edge would be available for ranging though ordinarily it will be of only limited extent. Stereoscopic methods are comparatively indifferent to general target shape. For the fixed reticle arrangement, however, greatest accuracy will result for an extended vertical edge favorably placed with respect to the reticles. On the other hand, since the vertical separation of the two images of ortho-pseudo is fixed, then depending upon the size, shape, and attitude of the target, the images may partially overlap, with the attendant psychological difficulty of reconciling the existence of two things in the same place. Again, this arrangement will be most sensitive when nearby vertical edges are available for comparison for both ortho-pseudo arrangements.

Effect of Variables

Tracking Errors. A principal limitation of present-day range finders when used on rapidly moving targets lies in the effect of tracking errors. With the divided field coincidence, ranging ceases if the elevation tracking error is such that the target is not cut by the dividing line. Only partial remedy is provided by the use of the elevation-tracking-error compensation knob, since there will always exist a residual vertical motion. For fixed reticle stereoscopic, elevation tracking error is especially harmful, since accuracy declines rapidly with increasing separation of target and reticles. Furthermore, should the target image coincide with a reticle mark, the psychological difficulties referred to above will arise. The new arrangements here tested are largely free from the effects of tracking error. Simple coincidence, coincidence with filters or flicker, and ortho-pseudo are virtually unaffected, provided the target remains in the field of view. For the coincidence and ortho-pseudo strips arrangements, ranging is possible in all parts of the field, but it is necessary for the eye to wander from strip to strip as elevation tracking error proceeds.

Visibility Conditions. The ability to range will depend upon the amount of light available according to time of day, visibility, and seeing conditions. The divided field coincidence, coincidence strips, stereo reticle, and ortho-pseudo strips make favorable use of all the light available. For ortho-pseudo, however, the background of sky or clouds of one image overlaps that of the other and the loss of contrast under conditions of poor visibility may prove serious. For simple coincidence or coincidence with filters or flicker, this condition disappears when in range and should be less detrimental. It is worth noting that coincidence filters depend upon the existence of comparable intensities of light of two different wave lengths. If then, the target and its background are lacking in the green component, for example, ranging becomes difficult. However, since the removal of the filters might be instantly possible, the system could be reduced to simple coincidence.

Poor seeing conditions should affect all arrangements about equally, except that the twofold basic accuracy of the two ortho-pseudo arrangements will be offset by a doubling of this effect. This condition would not be marked except for targets near the horizon. Poor visibility affects the fixed reticle stereo in a peculiar way. This is because the observer must compare a hazy image of the target with a clear and sharp image of the reticles. Systematic errors are likely to result, especially since in practice it is customary to make the initial internal adjustment of the instrument by comparing a sharp internal target with the sharp and clear reticles. In all other arrangements, systematic errors of this sort are not to be expected since the images, whether for internal adjustment or for taking range, are of comparable intensities and sharpness.

Personal and Psychological Factors. Finally, some variation among the optical systems is to be expected

with respect to such matters as speed of learning, ease and speed of making range settings, fatigue, and psychological preference. In particular when the stereo reticle arrangement is out of range, the observer knows immediately in which direction to turn the ranging knob to make the necessary correction. The same is true for coincidence filters and divided field and for ortho-pseudo. However, for simple coincidence and coincidence with flicker, the appearance of the images is the same whichever the sign of the ranging error, and the observer must rely on trial and error knob movements. This not only increases the time required for making initial contact, but adds to the uncertainty of maintaining contact. The strip arrangements, both coincidence and ortho-pseudo, do not have this disadvantage, provided the observer is able to identify the particular strips being used, as would be possible if one set of alternate strips differed in color from the other. Such a correlation may be difficult in the presence of elevation tracking errors.

2.2.3 Performance Tests of the Optical System

For each of these eight optical systems it was possible to view each of three targets of simulated airplanes with variations in target size, attitude, and rate of apparent change of range. Elevation and azimuth tracking errors could be introduced and a condition of poor illumination and poor visibility or haze. The recording device consisted of a scale graduated in *units of error* [UOE] which was read to determine the observer's zero setting, and a battery of 16 clocks which recorded the deviation of the ranging wedges from zero under conditions of dynamic operation. The operation was an attempt to simulate field conditions with the instrument set to an error of about 100 UOE, in a direction unknown to the operator, so that he would first have to make initial contact and thereafter track the dynamic target in range. There were three groups of subjects selected in accordance with the criteria set up in the Army Field Manual. The first group of 21 men made a series of static tests for 4 weeks on the Navy Mark II Trainer and then 4 weeks on the testing apparatus. A second group of 19 selected men worked only on the tester for the 4-week period. The third group consisted of six men selected from the other two groups who stayed on and made a more exhaustive series of observations of the various optical arrangements of the tester involving both static and dynamic runs. They worked six 8-hour days per week for 12 weeks.

Preliminary Results

The results of the preliminary experiments for the static mean deviations in UOE of eight runs indicates the ortho-pseudo arrangement gave the best results, with coincidence divided field and strips, and stereo reticle not very different. Simple coincidence, coincidence with filters, and flicker are the worst arrangements when the field is viewed either monocularly or binocularly. The averages for the last four runs, presumably after some practice, do not substantially change the rank order although the magnitude of the error is reduced for every one of the arrangements. The time required by each observer to complete ten settings was recorded for each arrangement for the last four runs. Averaged for all observers, these times varied from 7 to 10 minutes except for the coincidence flicker which required 13 minutes. The observers complained that ortho-pseudo strips and especially coincidence flicker required excessive concentration, and also reported eyestrain.

In another experiment 15 dynamic runs were performed by the six observers of the third group. Simple coincidence, and coincidence with filters and flicker were performed with the binocular arrangement only because it was found superior or equal to monocular observation in the previous experiment. Divided field coincidence was omitted because of its similarity to coincidence strips. Readings were taken both without and with tracking errors in elevation and azimuth, with poor visibility, and irregular dynamic change as variables.

Effects of Variables

A study of the results indicates the harmful effect of tracking errors for the stereo reticle, coincidence, and ortho-pseudo strips is quite evident. On the other hand, poor visibility affects all arrangements rather uniformly. The run with irregular dynamic change indicated that familiarity with the pattern of change did not unduly affect the results of the other runs. It is evident that both coincidence and ortho-pseudo strips suffer excessively for the targets with unfavorable attitude under tracking error. The rank

order of the best values from smallest to largest errors are ortho-pseudo (1.9 UOE); stereo reticles (2.3); ortho-pseudo strips (2.5); coincidence strips (2.9); coincidence filters (3.5); coincidence flicker (4.0); and, finally, simple coincidence (5.0 UOE). The rank order for the mean for all conditions is not very different from that of the best values, being: ortho-pseudo (2.5 UOE); ortho-pseudo strips (4.1); stereo strips (4.9); and simple coincidence (6.3 UOE).

Because the ortho-pseudo arrangement had a lower dynamic mean deviation for every one of the tests, further experiments were undertaken. These tests were made with four of the six men of the third group who were now seasoned, trained observers. Only the ortho-pseudo and stereo reticle patterns were used for this comparison, with coincidence divided field introduced as a check. Various combinations of variables of tracking errors, poor visibility, poor illumination, and irregular dynamic change in range were introduced. In these tests the ortho-pseudo arrangement was consistently superior to stereo reticles. The grand means were 0.70 UOE for stereo reticles and 0.46 UOE for ortho-pseudo for all conditions. The grand mean for coincidence divided field was 1.2 UOE even though no results were taken with the two most difficult targets with tracking errors introduced. An analysis of the results suggest that the size and shape of the target are of importance only in the case of the split field coincidence and this may be a partial explanation for the poor showing of this arrangement.

In a consideration of the dynamic mean deviations the results indicate that the two stereoscopic arrangements are not markedly dependent upon the size and attitude of the target. For the basic runs, that is without any variables introduced, the errors are 20 per cent larger for stereo reticles than for ortho-pseudo. Tracking error has little effect on ortho-pseudo while the detrimental effect on the stereo reticle pattern makes the error increase 50 per cent over the basic one. For this arrangement, elevation and azimuth tracking errors were equally harmful. Poor visibility affected ortho-pseudo rather seriously but, under the conditions of the experiment, no worse than stereo reticles. Poor illumination proved to be only a limited handicap for either arrangement.

Results with Inexperienced Observers

In a subsequent experiment, CIT made an investigation of the relative merits of certain range finder optical systems when used by inexperienced observers. (188) The application was for short-based range finders to be required in great numbers and hence with a simple optical system. Accordingly, only simple coincidence, coincidence with filters, and stereo reticles were used in the tests. Because the range finder would be operated by comparatively inexperienced observers, the tests were planned to emphasize the learning aspect. Because the application envisaged rapid motion of the target and of the platform of the instrument, the effects of tracking error were given particular attention. The same instrument was used as in the former experiments. The subjects were 30 men chosen by selection with visual tests. These were divided into six groups of 5 men each to make random the order in which the runs were taken with the different optical arrangements. The results show the greater inherent sensitivity of stereo reticles as indicated by the static mean deviations. The curve for this optical system is relatively free from learning, dropping from slightly less than 2 UOE error in the first session and reaching a plateau at slightly more than 1 UOE by the third session. The curve for coincidence filters is consistently below that for simple coincidence for all five sessions of the experiment but only one value in either curve is below 3 UOE when this value is reached by the second session for coincidence filters. Tracking error adversely affects all three arrangements, stereo reticle being rather more affected than either of the coincidence arrangements.

When one considers the values of the dynamic deviations of the mean, stereo reticles no longer appear markedly superior. This is an indication that this arrangement is more subject to systematic errors than the coincidence patterns. One observer had extreme difficulty with stereo reticles under tracking error, being for the most part completely out of contact. His performance with this arrangement was quite normal without tracking error. From these results the investigators make the following conclusions. At the beginning of this program it was feared that stereo reticles might be inadequate in two respects; first, that it would take too long for an inexperienced observer to master it, and, secondly, that it would suffer unduly from large tracking errors. It now appears that stereo reticles are superior to either simple coincidence or coincidence with filters. Even at the beginning of the trials, it shows smaller values for the significant numbers. The values for the final

performances of stereo reticles ran from 30 to 70 per cent higher than comparable figures obtained in previous tests for seasoned observers. Also, it is likely that an occasional observer will fail utterly with stereo reticle under tracking error.

These two CIT reports are presented as supporting data to a Report to the Services issued by the Fire Control Division of NDRC. (27) The results are summarized here briefly but no recommendations are made to the Services.

2.2.4 Performance of the Mark 40 Range Finder

When Modified by Color Differentiation and Flicker

In regard to several of these matters, a Bausch and Lomb Optical Company report contributes further information. (115) The report is divided into two parts. The first deals with the performance of the Navy Mark 40 Range Finder modified by the inclusion of color differentiation of the two target images and the inclusion of intermittent exposure of the target images by a flicker technique, either singly or in combination. It was found that when the images were interchanged about ten times per second at the eyepiece by means of a Polaroid system, precision of ranging improved from ±247 UOE to ±165 UOE for the average of four observers. When the images were differentially colored by means of red and green filters over the respective end-windows, the precision of two new observers with normal color vision improved respectively from ±2.89 to ±2.12 UOE. These same observers had, however, been previously improved to a greater extent than this by the flicker feature from ±2.89 to ±1.86 UOE. When both the flicker and color accessories were in use, one new observer improved in precision from ±3.31 to ±2.35 UOE. Two other observers obtained poorer precision with the plain instrument. One observer who was partially color blind was not significantly affected in his precision by the addition of the color feature, whether or not flicker was also present. Also a particular weather condition may affect the flicker and flickerless operation differently. Heat waves or atmospheric boil appears to reduce precision less when flicker is present than when it is absent. These results confirm the previously reported results from California Institute of Technology in emphasizing the increased precision when flicker is introduced. They do not confirm the finding of increased color alone, except when the observers were relatively untrained. Hence for flicker the gain is very similar for the Bausch and Lomb and CIT experiments when expressed in per cent—the values being 33 and 25 per cent respectively. The results for color alone are quite different, however, being 24 per cent for Bausch and Lomb and 5 per cent for CIT.

When Target is Off-Center in Visual Field

The second part of this report has to do with ranging with the target off center in the visual field. It was found that no significant change in accuracy occurs with the Mark 40 Range Finder when the target is placed as much as 10 degrees of apparent field angle below, above, or to either side of the center. Precision falls off no more than 0.5 UOE in any of these meridians and it is believed that these losses probably have a largely optical and not essentially perceptual basis. Expert stereoscopic range takers perform with great inaccuracy and with poor or extremely poor precision in attempting, without special training, to range on a target 6.5 to 10 degrees of apparent field angle below the central reticle marks of stereo range finders. Three out of four inexpert stereo range takers learned in a few days to range with acceptable precision on targets as much as 5 degrees above or below the fiducial mark. Only one of the three attained acceptable accuracy. The inaccuracies of the other two were systematic and apparently due to the effects of torsional movements of the eyeballs, normal in those observers, upon their stereoscopic vision. For them, the perceptual plane of the reticle was a sloped or warped surface. The fourth observer, allowed the same amount of practice as the other three, could not learn to range off center with either acceptable precision or accuracy.

2.2.5 Optical Systems in Relation to Field Types

A report from the Princeton Branch of the Frankford Arsenal describes modifications to the M6 Stereoscopic Trainer enabling it to be used for experiments to determine comparable results from different optical arrangements rapidly and easily. (262) This modification would provide ortho-pseudoscopic, stereoscopic reticles, ortho-pseudoscopic stereo

coincidence, split field coincidence, both erect and inverted fields viewed binocularly and monocularly. Various targets may be introduced including vectographs and Kodachrome stereo-pairs, and even actual external targets may be used for ranging. These modifications are described in detail in the report.

This instrument was used in a comparative study of types of field which are reported in another study. (241) Eight field types were used: superimposed coincidence, erect coincidence, invert coincidence, ortho-motion, invert coincidence pseudo motion, invert ortho-pseudo, erect ortho-pseudo, ortho stereo with reticles, and pseudo stereo with reticles. Three trained observers ranged on three targets which were vectographs of a telephone pole, a tank half hull down, and a tank head on. Because of the nature of the targets no measure of true range could be determined. The results indicate that, for targets of this sort, superimposed coincidence is definitely inferior to all of the other field types in both precision and consistency of ranges. Erect ortho-pseudo appears inferior in precision, though its consistency is good. Pseudo-stereo with reticles is inferior in consistency.

In another report by the Frankford Arsenal, Princeton Branch, is reported a comparative study of invert-foreground and invert-sky in both monocular split-field coincidence and ortho-pseudo stereoscopic types of field. (242) Averaged over all observers, for simulated ground targets, no significant differences in consistency or precision were found between coincidence and ortho-pseudo presentation or between invert-sky and invert-foreground fields. Individual observers showed marked differences, however, in performance with respect to type of presentation. One observer did well on ortho-pseudo and not so well on coincidence, while another performed well with coincidence and poorly with the ortho-pseudo presentation. No significant differences between observers were shown for type of inversion.

Still another comparative study of types of field is reported by the Princeton Branch. (261) Four types of field were compared; invert coincidence, invert ortho-pseudo, stereo with reticles, and superimposed coincidence. In the invert fields, the upper half field was erect and the lower half inverted because the previous work had shown that the results with invert fields are unaffected by the choice of upper or lower half field for inversion. Six vectograph photographs of ground targets were used and these were ranged on by two experienced observers. The results indicate that, in regard to precision, superposed coincidence gives the largest spread for both observers and for all targets. As between the remaining fields, the results differ with the observer. One performed best on stereo while the other's stereo performance was somewhat worse than either of the other fields. As between invert coincidence and ortho-pseudo there was no consistent superiority for either field with either observer. As regards consistency, the results show clearly that superposed coincidence is definitely more variable than the other fields. Between the remaining fields, the case is not so clear. In general one observer did best on stereo reticle while the other showed no consistent superiority with either ortho-pseudo or stereo reticle.

2.2.6 Precision, Consistency and Accuracy of Visual Range Observations

A fundamental study of the precision, consistency, and accuracy of visual range observations, both of the stereoscopic and vernier types, is reported by the Harvard Fatigue Laboratory (267) and is attached as supporting data to a Report to the Services issued by the Fire Control Division of NDRC. (5) This report to the Services merely passes on the Harvard report for their information and makes no recommendations.

The Harvard report points out that a systematic study of the laws of stereoscopic acuity may be approached from the standpoint of commonplace stereo vision or of telescopic stereo vision. Each mode of approach possesses its own peculiar advantages and disadvantages. The major advantage of using commonplace vision ("free space") at the beginning of a general investigation lies essentially in the fact that an almost unlimited number of ocular variables may be studied with a relatively small expenditure of time and effort. The chief disadvantage of this approach resides in the fact that one is sometimes uncertain whether the commonplace results apply to telescopic vision.

There is one problem, however, basic to both methods of approach, which may be studied with profit under commonplace circumstances. One may undertake to discover the psychophysical conditions, general or specific, under which stereoscopic vision is most precise (i.e., minimal variation for a single set of observations); maximally consistent (i.e., the observed range does not vary from day to day any

more than is expected by random sampling from a homogeneous universe); and sufficiently accurate (i.e., the departure of the observed range from true range is acceptably small). The need for this kind of undertaking arose from the fact that the fundamental laws governing these three measures of stereoscopic acuity, any one of which can be varied independently from the other two in the laboratory, were almost completely unknown.

Therefore the Harvard experiment sought to determine the general rules which govern the influence on stereo acuity of alterations in observational circumstances as they have been systematically varied under a variety of controlled conditions and also, by further investigations, to isolate some of the conditions producing optimal effects. Experiments were carried on concerning the performance of normal observers under commonplace binocular stereo conditions and under monocular vernier observation. In most of the experiments, enough measurements were obtained to be statistically reliable. Some of the more reliable results show conflicting indications. Others have proved difficult to understand. Still others seem to have no practical application. At best, the net result is one of considerable complexity. From beginning to end, moreover, it was necessary to conduct the investigations at an empirical rather than at a strictly rational level. At the empirical level, it is believed that an advance has been made and that the results are sound enough so that the investigators could turn profitably to the study of stereo vision under telescopic conditions. For example, the investigators feel certain that they have succeeded in the attempt to specify some of the general conditions under which the precision, consistency, and accuracy of stereo range observations will — from one time to another during any given day, and from one day to the next, over a period of several months — remain essentially constant at a value equal to 1 or 2 seconds of arc.

Conclusions

The general conclusions deriving from these experiments, detailed below are:

1. Coincidence acuity increases with target distance, and approaches a limit as the eye approaches a relaxed state of accommodation. This result confirms the Aubert-Foerster effect.

2. Stereo acuity is a variable quantity. For the same target reticle assembly, the so-called "minimal" parallax angle can be made to vary systematically with the convergence and accommodation of the eyes, with the apparent distance of the target, with the vertical attitude of the eyes, with the mode of fixation, with observational criteria, and in minor ways with a number of other factors. The smallness of an observer's "minimal" parallax angle, therefore, depends on conditions prevailing in the observer.

3. Nonetheless, stereo acuity is good and dependable if special psychophysical conditions are properly controlled. If the converged distance equals the accommodated distance equals the apparent distance equals the target distance (remotely situated), then the precision, consistency, and accuracy of commonplace stereo range observations are of the order of approximately one second of arc. When these conditions are violated, the observations suffer a reduction in precision and consistency. The amount of reduction depends on the conditions violated and the magnitude of the violation. The reduction may be 100-fold or more. In other words, (a) when the conditions are violated, stereo acuity is low. Precision usually exceeds consistency. Consistency may be of the order of 1 or 2 minutes of arc. (b) When the conditions are all fulfilled, stereo acuity is high. Consistency exceeds precision. Accuracy may exceed consistency. Precision, consistency, and accuracy all equal about 1 to 2 seconds of arc. Hence the general final conclusion may be drawn that the accuracy of stereo range measurements can be controlled.

Details of Experiments

In the first experiment, on which these conclusions are based, the precision, consistency, and accuracy of stereo range observations were measured at each of a number of target distances. The converged, accommodated, apparent, and target distances were kept equal throughout. The experiment sought to challenge the prevailing notion that the "minimal" visual angle for stereo vision remains constant when the distance is varied. It was found that precision and consistency increased as the target distance was increased. This finding, which is the stereoscopic counterpart of the Aubert-Foerster effect for ordinary visual acuity, has definite implications for telescopic stereo range finders. For high stereo-acuity (1 to 2 seconds of arc), the accommodated distance of the target and reticle in apparent visual space should exceed 20 to 30 feet. It was also observed that the inaccuracy of the range measurements decreased

as the target distance increased. The instruments devised for this and subsequent experiments are described in the text. A number of very highly trained observers were used throughout.

Effect of Distance. The fact that acuity was high for remote distances raised the question concerning the possibility of securing even higher values at still greater distances. Experimental conditions were arranged which allowed the observers to demonstrate their ability when the converged distance was equal to, or nearly equal to, infinity. Under these conditions the mean variation of stereo observations was found to be of the order of 1 to 3 seconds of arc at distances greater than 10 meters when the proper conditions were fulfilled. The mean variation of the means of these stereo observations was less than the mean of the mean variations. When the conditions were violated, on the other hand, the average of the mean variation of the stereo observations was increased to about 6 seconds of arc. The mean variation of the means of the observations, furthermore, was greater than the mean of the mean variations.

This kind of situation is not what one expects in observations behaving normally in accordance with the law of error. Rather it is what one might expect from results obtained by sampling in a biased manner from a single homogeneous population, or by sampling in a random manner from one universe at one time and, in the same manner, from each of a number of others at other times. If biased sampling represents the situation, then the fact that the average of the mean variations is smaller than the mean variation of the means should be expected, and the latter index is the measure to use in general for predicting the variability of the stereo range observations. If different universes have been sampled from one time to another, a similar admonition is in order. In either event, the same experimental solution is indicated. One population (or bias) should, if possible, be consistently chosen by the observer.

Inasmuch as these were highly trained subjects, there can be little doubt that each observer did his best under both sets of circumstances. The investigators believe that the principal reason why the mean variation of the means was greater than the mean of the mean variations, when the eyes were verged to infinity, is that normal eyes invariably accommodate to the converged distance and thus the retinal images of the target and reticle suffered a loss in definition. Such a situation produces a visual conflict. If the observer verges exactly to the target and reticle, he soon recognizes by trial and error experience that the definition can be improved by increasing his convergence. If the convergence is increased too much, however, double vision results. This abnormal state of affairs sets up a fluctuating tendency which could increase the mean variation of the averages of stereo observations not only because it provides an opportunity for different vergence-accommodation biases but also because, from one set of observations to the next, it provides an excellent opportunity for the occurrence of varying degrees of cyclotorsion and these different degrees of cyclotorsion will practically always produce differential changes in the apparent distance of the target with respect to the apparent distance of the reticle when either one is located directly above the other in the visual field.

Effect of Attitude. The next experiment was aimed at the control of attitude and its relation to accuracy. Three different attitudes of the eye were used: reticle centrally fixated, fixation midway between recticle and target, and target centrally fixated. The results show that the accuracy or range observations can be controlled, in absolute amount, by the proper direction of the observer's eyes. The effect itself can be understood simply in terms of retinal disparities produced by excyclotorsion (the summits of the eye recede from each other as the eyes turn imaginary axes through the foveas and the point of fixation) during each fixation. When the eyes turn about these axes, a constant angular turn produces a binocular retinal disparity which increases with the vertical distance from the foveas. Thus, as the observer fixated midway between the reticle and the target, and made his stereo setting accordingly, his results evidenced only a slight negative inaccuracy. However, as he fixated the reticle, then the target was seen relatively more remote in apparent space due to the increased disparity produced by the constant amount of excyclotorsion. To execute his task properly, therefore, the observer reduced the apparent position of the target, and his observed readings fell short of the true range. The same sort of reasoning may be applied to the situation in which the target was fixated, with the same result.

This effect can occur with the reticles now used in Army and Navy instruments. That it actually does occur is proved by reports from stereoscopic observers in the Services that they occasionally see the diagonal reticle marks in reversed perspective.

Effect of Stereo Acuity and Vergence Change. The next experiment was aimed at a study of stereo acuity and vergence changes. As an observer fixates the target or the reticle in a stereoscopic range finder, the vergence of his eyes alters from time to time within the limits of binocular fusion and the experiment sought to determine the effect of such changes on stereo acuity. The physical distances of the targets ranged from 300 to 2,400 cm. The vergence was changed by means of a pair of crossed prisms placed directly in front of the eyes of the observer and with settings changing the vergence from +2 degrees 18 minutes to −2 degrees 18 minutes of arc. Such vergence changes would occasion changes in converged, apparent, and accommodated distance.

The results indicate that the precision decreases as the converged distance departs more and more from the target distance. The rate of this decrease in precision is not the same for all target distances. At the most proximal distance (of 300 cm) the rate of change in variability per unit of change in vergence is greatest. In other words, for short apparent distances, the precision falls off most rapidly as the converged distance is either increased or decreased. At the most remote target distance (of 2,400 cm) vergence changes produce very little effect on the magnitude of precision. In regard to consistency, for the most proximal distance there is a rapid decrease as the change of the vergence angle is increased. The trends showing the effect of vergence changes upon the accuracy of range observations are not regular. For remote distances, where the inaccuracy is very small, changes in the converged distance produce little effect on the magnitude of the measurements. At the more proximal distances, however, the inaccuracy varies considerably when the converged distance is no longer equal to the target distance.

Effect of Coincidence or Vernier Acuity. Still another experiment outlined in this Harvard report was concerned with coincidence or vernier acuity. The field of view, target, reticle, distances, and the adjustments were the same as those used in the binocular experiments but light was occluded from the left eye by a stop. In these experiments, the consistency exceeded the precision in all cases but one. At the shortest distance, the inaccuracy was large—varying from about −35.7 to about +150 seconds of arc for three observers. At the longest range, the inaccuracy was small, varying from −0.03 to +0.8 seconds of arc.

A comparison of the binocular and monocular results yields the following. The difference between the average mean variations is positive and large for short ranges. As the range is increased, the difference decreases up to about 20 to 30 feet. The difference between monocular and binocular precision is insignificant at more remote distances. The consistency differences behave in essentially the same manner as those for precision. The monocular accuracy results for two of the three observers are all positive. Thus, the average for the observed range is slightly greater than the true range at each of the six distances. For the third observer, most of the departures are negative. For binocular vision, these errors are considerably smaller at proximal distances. There is little difference, however, between the binocular and monocular results when the perceived distance of the target is great. The results of these experiments demonstrate that the precision, consistency, and accuracy of range measurements for binocular regard are better than those for monocular vision when the perceived distance of the target and reticle are short. When the perceived distance is great, the two modes of observation are about equally good.

Just Noticeable Differences

In the second half of this report, the investigators discuss the relation of just noticeable differences as compared with the equality settings described in the first section. These were obtained under both binocular and monocular viewing and for both proximal and remote distances. They are judgments of when the target appeared just noticeably nearer or further from the reticle. The reciprocal of a just noticeable difference [j.n.d.] is usually designated as a measure of differential sensitivity of the observer. In their earlier work the just noticeable differences and the precision measure of range estimates were believed to be of about the same order of magnitude for comparable conditions. They therefore argued that these two measures are probably determined by the same underlying physiological mechanism. The section under discussion presents data which indicates that this hypothesis is not consistent with all the facts. For binocular vision the magnitude of differential sensitivity is much less than the magnitude of the precision of range estimates for practically all distances. The trends are the same, however, as the j.n.d. diminishes as the target distance increases. The difference between corresponding proximal and re-

mote j.n.d. for any given observer, moreover, is least at the greatest distance. At more proximal distances, the corresponding proximal and relatively more remote values in some instances differ greatly, although in a number of other instances the two values are almost equal. The sum of the proximal and remote j.n.d. for any target distance has been known historically in psychophysics as the interval of uncertainty. In angular units, the magnitude of the j.n.d. in distance becomes progressively smaller as the target distance increases. The data for j.n.d. for monocular sensitivity also show, in all cases, the tendency to decrease with distance, and the rate of change is most rapid initially and then more attenuated. While the difference between corresponding proximal and remote values is often very great for any given nearer distance, for the more remote distances the differences are very small.

A comparison of the results regarding distance sensitivity as obtained under binocular and monocular conditions of observation reveals several points. First of all, the j.n.d. in both cases exhibits a tendency to decrease as a function of distance. The rate of change in this respect is greater for the monocular data, owing to the fact that the j.n.d. for proximal distances is much greater for monocular than for binocular observation, while the values for both conditions of observation at the greatest distance are of the same order of magnitude. The differences between proximal and remote values for a given observer and for a given distance are also greater for monocular than for binocular observation.

Magnification and Base Length
Stereoscopic Instruments

A final chapter of this Harvard report deals with problems of magnification and base length of stereoscopic instruments. In the magnification experiments large Zeiss terrestrial binoculars were employed using two magnifications of 0.8x and 12x which are in the ratio of 1 to 15. From the standpoint of geometrical optics, a 15-fold reduction in the precision of the range measurements is to be expected, if one assumes that the observer's stereo acuity remains constant for these two sets of conditions. If, however, one takes into account the fact that an increased magnification reduces the accommodated distance of all objects in the field of view, then, since the converged distance remains unchanged, when the target and reticle are properly centered, one would actually expect a decrease in stereo acuity with an increase in magnification. The results reported showed only a 3-fold increase in the precision and in the accuracy of the actual range settings when the magnification was increased 15 times. The observers' stereo acuity, therefore, was reduced to one-fifth of its original value, in seconds of arc, as the magnification of the target and reticle was increased. The advantage afforded by magnification was evidently opposed by some compensating factor—probably the accompanying reduction in the distance of the target as seen in telescopic space.

2.2.7 Study of Stereo Acuity and Telescopic Vision

Conclusions

Another experiment is reported in an attempt to obtain a rough estimate concerning the effect of magnifying the parallax angle per se, that is without magnifying the retinal images of the target and reticle. This was performed with a telestereoscope possessing a variable base. This instrument has the effect of greatly increasing the interpupillary distance of the observer and hence magnifies the parallax angle. It was found that the observers' stereo acuity was reduced as the base was increased. Stereo acuity for these observations was thus greater for the observer when he used the normal interpupillary distance than when he viewed the field with the aid of an enlarged base. Stereo precision was found to decrease continuously as the length of the base was increased. Hence as the range finder is increased, the converged distance is greatly diminished, as compared with the distance to which the eyes of the observer ought to be accommodated if the target and reticle images in his retinas are to be sharply defined. Still another factor which may be operating effectively to offset the optical advantages afforded by the large base is the factor of apparent size.

This group of experiments support the conclusion that stereo acuity is both good and dependable under the special conditions of the converged distance, the accommodated distance, the apparent distance, and the target distance all being equal. In this case, the experiments with commonplace vision indicate that the accuracy, precision, and consistency of stereo range observations are of the order of 1 or 2 seconds of arc. Too much emphasis cannot be

placed on the maintenance of this 4-fold equality, because when these conditions are violated, in any way whatsoever, the observations suffer a reduction in precision and consistency up to 100-fold or more. The amount of reduction will depend on the conditions violated and the magnitude of the violation.

These laboratory studies of stereoscopic acuity were continued at Harvard University for both unaided and telescopic vision. (283) Stereo acuity is ordinarily measured in angular units at the observer's eyes and is assumed to be independent of magnification, base length, and range when the eyes are used in conjunction with an optical instrument. If this measure is valid and the assumption correct in general, then the angular error of a stereo range finder, as measured at the instrument, varies inversely with magnification and base length, but is independent of range. This expectation issues directly from the well-known equation relating the angular range error to range, magnification, and base length.

The Harvard investigations were made under a variety of field and laboratory conditions and, in general, failed to bear out this expectation. Stereo acuity, as measured in angular units at the eyes of the observer, was not found to be independent of magnification and range. Instead, the results indicated that stereo acuity: (1) became poorer as the magnification increased at any particular range; (2) improved as the range increased for any particular magnification; and (3) was about 100 times better than is conventionally supposed.

An analysis of the conditions under which these results were obtained indicated that three different distance cues were available to the observers during the experiments. These cues were isolated physically, and the strength of the cues measured with reference to their effect on the observer's depth perception: (1) when all three cues were available; (2) available in pairs; and (3) available one at a time. All of these conditions were investigated in free space and as modified by telescopes of various powers. In considering the results of this analysis it was found convenient, and at times necessary, to express range errors in linear units. Most of the data, therefore, is expressed in yards or in per cent yards.

The results may be summarized as follows. A series of field experiments was performed in order to determine the relation between stereo acuity and magnification. The experiments were carried out both on land against a terrestrial background and on the water against a fairly uniform background of sea and sky. Measurements were obtained for a number of different magnifications, varying in power from 1x (the unaided eye) to 40x, and for different ranges, varying from 50 to 6,400 yards or more than 3 miles. For each of the three highly trained observers who served in all the experiments, the results were essentially the same, and they present the following indications.

The relation found between magnification and stereo acuity indicated that the angular error at the eye was not constant, but increased in direct proportion to the increase in magnifying power. Expressed in per cent units (=100x$\triangle R/R$) the error was constant and independent of magnifying power. The relation found between range and stereo acuity indicated that the range error in per cent was not proportional to the range, as conventional theory assumes. Instead the per cent linear error was found to be nearly, though not exactly, independent of range. Moreover, the per cent error of the observations was unexpectedly low. For any of the ranges or magnifying powers employed, the average mean variation or the mean variation of the average adjustments were always less than 1 per cent. Even the averages for insensitivity did not exceed 5 per cent at any range and, for the more remote distances, they also fell below 1 per cent.

Details of Experiments

The results of the field experiments led to two lines of further experimentation in the laboratory by the Harvard group: (1) a verification and understanding of the relation between magnification and stereo acuity, and (2) an analysis of the properties of the visual end point which gave such high precision, consistency, and sensitivity.

To obtain the laboratory results, the original study was repeated under conditions which approximated as nearly as possible the fundamental conditions of the field experiments, although the ranges used were necessarily reduced in the laboratory to 20 to 60 yards. The angular size of the target and reticle were not kept constant, but were allowed to vary naturally with range and magnification, as in the previous experiments. The laboratory results confirmed the relations indicated above. The angular error at the eye was found to increase in direct proportion to the increase in magnification. Ex-

pressed in terms of per cent error, the error of the observations was independent of magnifying power. For the three distances available in the laboratory experiment, the results again indicated that the range error, in yards, was proportional to the range, rather than to the square of the range. Furthermore, the magnitude of the range error was found to be even smaller than extrapolation from the field data would suggest. This difference may be attributed to the more accurate controls which were possible in the laboratory study.

The Harvard group then made an end-point analysis of stereoscopic acuity in the laboratory. The laboratory analysis of the properties of the stereo end-point was conducted in two series of experiments. The first series was carried out for free space, that is, the observations were made with the unaided eye. The second series involved observations under the conditions of telescopic vision. An a priori analysis indicated that there are three primary visual cues available to the observer for distance judgment when a target recedes from or advances towards the observer as in the magnification experiments. These cues are: (1) changes in the binocular parallax angle; (2) changes in apparent size; and (3) changes, at the observer's eye, in the wave front of the light arriving from the moving target.

Experiments were performed to determine the observer's acuity (1) when all three changes were simultaneously available, (2) for each of the cues taken individually, and (3) for different pairs of cues. The results for free space showed that the greatest precision, consistency, and sensitivity were obtained when all three cues were simultaneously available for distance determinations.

The relative contribution of each of the three visual cues was a variable factor, depending upon the range at which the results were obtained. At near distances, where the change in disparity which accompanies a small change in range is large, disparity was found to be a very important cue; while at more remote distances of approximately 50 yards, where the binocular parallax angle is small, the disparity cue was relatively unimportant. At each range, however, elimination of any single cue resulted in an increase in the error of the adjustments. The increase in error resulting from elimination of the size cue was very small at all ranges, indicating that size change was not so important for distance judgments as the wave front and the disparity cues. It was also found that the observer's sensitivities to the three individual cues, when measured independently, summated to give the sensitivity which was obtained for the end point in which the three cues were simultaneously available. This summation of sensitivities seemed to suggest a reasonable basis for the high acuity found in the original field experiments, where all cues were available.

A similar experimental analysis was then carried out for observations in telescopic space, using a number of different magnifying powers from 1x to 40x. The net result was the same as in the previous experiment in which observations were made with the unaided eye. The greatest acuity was found for the end point comprising all three cues. The elimination of any one cue always resulted in a loss in precision, consistency, and sensitivity. The loss resulting from elimination of the size cue was again found to be very small, indicating that the change in apparent size is a relatively unimportant factor. However, in contrast to the results for free space, in telescopic vision the changes in wave front per se are so reduced by the telescope that this cue alone was inadequate for the perception of changes in apparent distance. Nonetheless, when this cue was eliminated from the visual end point, the measurements suffered a considerable loss in precision, consistency, and sensitivity — indicating that changes in wave front, even when considerably reduced, do contribute in an important way to the efficiency of the end point for distance determinations when combined with another cue. Of all three cues, the contribution provided by binocular retinal disparity was found to be of greatest relative importance. The results obtained when binocular parallax was the only available cue, however, were poor as compared with the results for the end point comprising all three cues. This study is being continued under telescopic conditions using instruments designed to magnify rather than reduce the wave front differences.

This group of experiments performed at Harvard University have demonstrated that stereoscopic acuity is a complex variable, whose magnitude depends on the cues available to the observer. When all the proper cues are available, stereo acuity is much higher than considerations based on the geometry of parallax per se would lead one to expect. This demonstration suggests the possibility of designing and constructing a portable short-base range finder for which the range error would be of the order of 1 to 2 per cent. This development is under way at the Harvard Laboratory (March 1945).

Chapter 3

FIELD COMPARISON OF INSTRUMENT TYPES

3.1 INTRODUCTION

A NUMBER of field studies were conducted at Fort Monroe in which instruments of different types were operated simultaneously against fixed ground and aerial targets in order to obtain comparative data in regard to their performance. These comparative tests were all conducted by the Princeton Laboratory at Fort Monroe.

3.2 COINCIDENCE AND STEREOSCOPIC RANGE FINDERS

The first of these reports is concerned with the comparative test of coincidence and stereoscopic range finders. (353) In these tests the American stereoscopic Height Finder M1 was operated against the British coincidence type Range Finders FQ 25 and UB 7, in ranging on fixed ground targets, moving naval targets and moving aerial targets. The coincidence and stereoscopic methods utilize the same basic principles of geometrical optics for the determination of the distance to a target. The two methods differ radically, however, in the nature of the criterion presented for human judgment. These British instruments were of the split field coincidence type. American crews were being trained at Fort Monroe to operate the coincidence instruments but this plan was dropped when six British seamen, who were experienced range takers, were made available for the tests. Until recently the British Services had tended strongly to the coincidence type of instrument while the American Services had adopted the stereoscopic principle for long-base instruments at least. The decisions of both the British and American Services apparently grow out of different interpretations of the experience of the Battle of Jutland in World War I and are of no concern in this place.

Tests were run in November and December 1941 using the British seamen on the British instruments and experienced American observers on the Standard M1. Bad weather conditions and various experimental difficulties and mishaps made it impossible to obtain a really satisfactory quantity of data before the tests had to be terminated. Fixed target readings were made on targets from 2,700 to 14,500 yards. Only five aerial courses could be recorded and these were all level flight courses, at altitudes of 3,000 to 4,000 yards and slant range between 4,000 and 12,000 yards. Continuous contact was used. Nine courses were obtained on slow moving naval targets at ranges from 4,000 to 12,000 yards. In these latter courses continuous and broken contact were used at different times.

It was found, throughout the tests, that the performances of the various instruments were more nearly alike when measured in external units (reciprocal range) than when measured in terms of error at the observer's eye, in spite of marked differences in physical dimensions of the instruments. The American M1 has a base length of 4.5 yards and used 12 power; FQ 25 with a 6-yard base used 28 power and UB 7, a portable instrument, has 25 power and a 3-yard base. The coincidence instruments did not use internal adjusters but were calibrated on targets of known range. In other words, the net performances of the different instruments were essentially comparable although the instruments exhibited varying degrees of efficiency in performance relative to their size. On aerial courses precision errors of the four instruments were about alike when measured in reciprocal-range units. In UOE, the FQ 25 had comparatively poor precision, while the UB 7, for three of the five aerial courses, had very small precision errors. The number of aerial courses was too small to yield much information about consistency of observations from one course to the next.

For the naval target courses, one American instrument was not operating. Precision errors of the other three instruments were similar to those on aerial height courses. In reciprocal-range units the three instruments had comparable precision. In UOE the FQ 25 was worse and the UB 7 was better than the American M1. Consistency error of the UB 7 was smaller than that of the M1, even when measured in reciprocal-range units, while the FQ 25 was similar in consistency to the M1, again in reciprocal-range units.

On ground targets the same general situation holds. Consistency errors of the four instruments over the 9-day period were the same when measured in reciprocal-range units. Again the UB 7 was better than the stereoscopic instruments in UOE and the

FQ 25 was worse. Consistency over the 9 days was not perceptibly worse than daily consistency for any of the instruments. In other words, the readings over the 9 days did not scatter in total more than did readings for a typical day.

An analysis of these results leads to the following conclusions. (1) Performance of the coincidence and stereoscopic instruments was about the same when range errors were measured in yards. (2) The UB 7, however, with a virtual base length smaller than that of the American stereoscopic instruments, was more efficient than the stereoscopic height finders in terms of performance for its size, while the large coincidence instrument, the FQ 25, was less efficient in this sense. This situation held for all types of target—fixed ground, naval, and aerial. (3) The UB 7 is somewhat better than the American instrument in consistency on naval targets, even when measured in external units.

This report is attached, as supporting data, to a Report to the Services issued by the Fire Control Division of NDRC. (20) This points out that the tests indicate no important difference in the precision obtainable from the two types of instrument—coincidence and stereoscopic. They do indicate, however, that the difference in performance between large and small instruments is by no means as great as would be anticipated from simple geometrical optics. The report concludes with the belief that stereoscopic and coincidence acuities are about equal. Under favorable conditions existing instruments of the two types perform about equally well, and the choice between them for any given purpose must be based on matters of convenience related to the particular conditions under which they are to be used.

3.2.1 Ortho-pseudo Modification

A second comparative study was made at the Princeton Laboratory at Fort Monroe between the standard M1 Height Finder and an instrument modified to the ortho-pseudo system developed at Eastman Kodak Company. (351) This instrument is described in an Eastman Kodak report (204) and will be described in some detail in Section 17.3, Chapter 17, Part IV. Here it is sufficient merely to indicate that the Eastman design is of the stereoscopic sort and was built into the case of the standard M1 Height Finder. Instead of a fixed reticle it presents to the observer a field in which he sees two images of the target. Manipulation of the range knob causes one of these images to apparently approach and the other to apparently recede from the observer. The task of the observer is to bring the two images of the target to the same stereoscopic distance on each side of a dividing line through the horizontal diameter of the field. This instrument was shipped on December 22, 1941 from the factory at Rochester, New York.

Comparative tests were made from January through April 1942 after experienced stereoscopic observers were given a week's practice with the ortho-pseudo modification. All instruments were charged with helium for temperature stability. During the first month a systematic schedule of tests on aerial courses was followed, using courses explicitly selected for this purpose. Level and dive courses, and crossing, approaching and receding courses at various ranges were included. All of these courses were run at an altitude of 10,000 feet. Observations on fixed ground targets were also included during this period. Early in March other observations were taken on aerial courses at altitudes of about 7,500 feet and of the level crossing type. Later in March and through April, observations were taken on ground and aerial targets using, as observers, students in the Stereoscopic Observers' Course of the Coast Artillery School.

It is not easy to estimate the performance limits theoretically attainable by the M1 Height Finder. There is some basis for expecting that the instrument ought to have, in reading height of an aerial target at, say, 2,000 yards altitude and 5,000 yards slant range, a precision error of about 5 yards and a consistency error of about 1 or 2 yards. Actually, precision and consistency of this order are not often attained. A realistic estimate of performance at that time, under good conditions, was a precision error of about 10 yards and a consistency error of 12 or more yards for the aerial target described above. There was good reason to expect that the ortho-pseudo instrument should have a smaller precision error than the M1 Height Finder. This is true because of the fundamental difference in the methods used in the two instruments to measure distances. To the observer, the apparent depth separation between the ortho and pseudo images is twice the sep-

aration between target image and reticles in the M1 instrument. Doubling the depth separation theoretically should improve precision by a factor of two, since the apparent error in settings is twice as noticeable to the observer as it would be for the same setting on the standard instrument. Also the absence of reticles in the ortho-pseudo instrument should tend to eliminate the difficulties associated directly with the reticle in the M1 Height Finder. Haze, for example, between the observer and the target creates a distance cue which disturbs the comparison with a reticle which is not affected by haze. Since the comparison in the ortho-pseudo is between essentially identical images, the presence of haze should cause less difficulty. Another advantage derived from leaving out the reticles lies in the fact that the azimuth position of the target is then unimportant to the observer as long as the target is in the field of view. In the reticle instrument, this centering of target near the fiducial line of the reticle makes a difference to the observer, as is indicated in Chapter 10 of this report. On the other hand, poor elevation tracking, which causes the target image to move up and down in the field of view, might cause considerably more difficulty in the ortho-pseudo arrangement than in the M1 instrument, because of the split field in the former which causes the two images to move in elevation in opposite directions.

On the basis of approximately 5,000 recorded observations made by 12 observers on the ortho-pseudo instrument the following results were found. Throughout the test, the performance on the ortho-pseudo was always at least as good as that of the standard instrument. On level aerial courses, the ortho-pseudo sometimes proved superior to the standard instrument, in either precision or consistency or both. The extent and character of the superiority varied from observer to observer. Two highly experienced observers showed consistency about twice as good on the ortho-pseudo as on the standard M1; the consistency of an equally experienced observer was about the same for both instruments. The situation was similar with respect to precision, which was about twice as good on the ortho-pseudo for two observers and the same for one. Hence, for one observer the precision and consistency were both better for the ortho-pseudo, and for the other two observers, one had better consistency and the other better precision with this instrument. There was no detectable difference in performance of the two instruments on dive courses. The dive course performance of both instruments was so poor that differences of the order of magnitude found elsewhere could not have been detected.

On fixed ground targets the two instruments performed about equally well except in the case of student observers on the 14,000 yard target. On this target, both their consistency and precision were better for the ortho-pseudo than for the M1 Height Finder by a factor of about two. The performance, with the ortho-pseudo of four experienced stereoscopic observers on all fixed targets and of the student observers on the 2,920 yard target was about the same as that on the standard instrument. Since the M1 Height Finder was a more familiar instrument to the observers than the ortho-pseudo, it is possible that the relative merit of this latter instrument might be somewhat underestimated. However, as tests were run which determined no real learning with the ortho-pseudo instrument by already experienced stereoscopic observers, this factor is probably not important. No real learning seemed to take place since all men read as well within a few days as they did at the end of the several months test. It is interesting to note that whenever the instruments were different in performance, the ortho-pseudo was the better by a factor of about 2. Although this factor of 2 is in agreement with theoretical expectation, this does not prove that the doubling of the angular magnification in the ortho-pseudo was entirely responsible.

The performance of all observers with the ortho-pseudo on level aerial courses did not show improvement in both precision and consistency over performance on the standard instrument. Each observer showed improvement in at least one or the other. One observer was more consistent with the ortho-pseudo, another read with greater precision, and the third showed improvement in both types of error. The results from these three most experienced observers, therefore, indicate that it cannot be asserted that, regardless of the observer, the ortho-pseudo is superior to the standard M1 with respect to either consistency or precision. What can be said is that the ortho-pseudo is at least as good as the M1 with regard to either type of error, and that each of the test observers showed improvement in at least one type of error in reading on the ortho-pseudo.

In regard to course corrections, two observers generally read shorter on the ortho-pseudo than on the standard instrument and the third test observer read longer. For the two observers who read short, there was also a tendency for the corrections to have less scatter on the ortho-pseudo than on the standard instrument.

On the basis of these findings, the Princeton Laboratory recommended, other things being nearly equal, that the ortho-pseudo type of instrument be preferred over the standard reticle-type instrument.

These data are attached to a Report to the Services issued by Fire Control Division of the National Defense Research Committee. (21) After summarizing the situation this report states that, when all the available information is taken into account, there appears to be good reason to believe that a well-designed ortho-pseudoscopic range finder in the hands of a well-trained crew would be more accurate, and more consistently accurate, than any other type of instrument so far devised. In time of peace, or if the procurement of optical range finders were not so difficult, an energetic prosecution of this development would obviously be warranted. Under the then existing circumstances, the situation was not quite so clear and the opinion of the Services as to the desirability of further work at that time was invited.

Detailed results of the experiments performed during the first month of the comparative ortho-pseudo M1 tests will be found in a study by the Fort Monroe Princeton Laboratory. (511) These results have to do with observations on fixed targets by experienced and student observers and with aerial courses of both level and dive type.

3.2.2 The German R 40 Range Finder

The Aberdeen Proving Ground reports comparative tests of the German 4-meter range finder R40 with the standard U. S. Height Finder M1. (46) The experiment was to determine the relative accuracy of the two instruments. The German instrument is described in a Frankford Arsenal report. (228) The instruments were tested by reading slant ranges to three kinds of targets: fixed terrestrial targets, the moon, and aerial targets. The range readings were converted into convergence angles and compared for both precision and consistency. The internal adjustments were made on fixed targets at known ranges.

It was found that the precisions with which it was possible to read on fixed targets were 0.492 seconds of arc with the M1 and 0.624 seconds with the R40. On the moon the precisions were 2.32 seconds for the M1 and 2.27 seconds for the R40 and the accuracies were 3.27 seconds for the M1 and 5.76 seconds for the R40. On the airplane targets, the positions of which were determined by ballistic cameras, the observers read slant range by the continuous contact method and photographs of the range dials were taken once a second. The precisions for aerial targets were 2.76 seconds for the M1 and 3.38 seconds for the R40 and the accuracies were 3.74 seconds and 4.74 seconds respectively. The M1 was charged with helium and the R40 was not so charged.

On the basis of these results, the Aberdeen group concludes that the apparent superiority of the M1 instrument is real but that the difference between the two instruments is small. They further state, in all tests with both instruments, any errors due to temperature stratification of the gas inside the instruments were small enough to be completely covered up by the other errors present. These results cannot be considered as final, because an examination of the tabular data indicates that there were large observer differences. Furthermore, the observers were not rotated between the instruments. The question can therefore be raised as to whether the differences in performance are due to the fact that the M1 observers were on the average slightly better than the R40 observers, rather than to any instrumental differences. Another unfortunate aspect of this study is that no comparison was made between the two instruments in regard to consistency or day-to-day variation of range readings. It is especially in respect to greater long-time stability that one might expect the German instrument to be superior to the M1 because its construction is aimed to this end.

At the Aberdeen Proving Ground, comparative tests were made of the German R40 range finder and the American Height Finder M1, both reading slant range. (47) Readings were taken on fixed terrestrial targets, the moon, and aerial targets. Internal adjustments were made on fixed targets at known range. The superiority of the M1 instrument was demonstrated throughout for better consistencies of internal adjustment readings and better accuracies and consistencies for all three sorts of external target. The differences between the two instruments are small, however.

3.2.3 Mickey

Still another comparative study by the Princeton Laboratory at Fort Monroe reports the performance of the M1 stereoscopic Height Finder in ranging on aerial targets with "Mickey," an early form of radar developed for antiaircraft ranging. (361) Mickey was later adopted by the Army as SCR-547. This test was made in August 1941, early in the development by the Bell Telephone Laboratories of portable radar sets to be used for this purpose. In all, 125 aerial courses were flown and about 50 of these were analyzed. The range varied from 1,000 to 18,000 yards. In some courses the range was constant, in others it increased or decreased at varying rates, or reversed its direction several times. Both level and dive courses were included. Highly experienced stereoscopic operators were used on the experiment. The statistical analysis of the results indicates, for Mickey, the precision error ranged from 5 to 78 yards, with a mean precision error for all courses analyzed of 27 yards. Seventy-five per cent of all precision errors lay between 16 and 36 yards. The consistency error for Mickey is estimated at 25 yards. Average course errors ranged from −16 yards to 87 yards with a mean of 25 yards and standard deviation of 25 yards. Sixty-eight per cent of the average course errors lay between −1 and 45 yards. The standard deviation of total range error is about 25 yards up to 7,000 yards range. It then increases, averaging 33 yards for all ranges up to 10,000 yards. The range error is relatively independent of range for Mickey as compared with the M1 Height Finder, which is subject to errors proportional to the square of the range. The optical Height Finder M1 appears superior to the radio range finder Mickey for ranges less than 3,000 yards; they are equal for ranges between 3,000 to 5,000 yards; and Mickey appears superior for ranges greater than 5,000 yards. Experiments designed to discover some of the major sources of error in Mickey were unsuccessful.

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PART I

ERRORS IN STEREOSCOPIC INSTRUMENTS AND THEIR CONTROL

Errors in ranging may be classified as: (1) those inherent in the design, construction and adjustment itself; (2) those brought about by external physical conditions such as disturbances in the atmosphere through which the target is viewed, and (3) those errors which are inherent in the operator or his method of operating the instrument. Chapters 4 to 8 deal with the first of these categories. The other two are dealt with in Chapters 9 to 12.

Sources of error in the instrument itself had not been analyzed at the beginning of this war, although such inherent errors were known to exist. The studies reported in these chapters show how, after the contributing elements were located, each factor was investigated independently of the others and a corrective devised for each defect.

Failure to focus the image uniformly in the reticle plane is called perspective error. Sections 4.1 and 4.2 present a group of studies which show that if the light beam through the objective lens can be restricted to the central portion of this lens, these errors will usually be reduced. This narrowing of the beam, and its limitation to the central portion of the optical system, can be accomplished by cutting down the size of the circular openings at the end windows or by introducing similar stops near the objectives. In the design of new instruments, adjustable internal stops are recommended, but perspective errors in existing range finders can be reduced by the addition of adjustable end-window stops. In either case, perspective errors are least when the openings are as small as are consistent with getting a sufficient amount of light through the optical system.

The improper spacing of the eyepieces, or improper interocular setting, usually causes ranges read too short when the eyepieces are too near together and too long when the eyepieces are too far apart. Section 4.3 gives a digest of a group of studies which relate the interocular setting to the interpupillary distance [IPD] or to the interaxial distance [IAD] of an observer's eyes. The IPD is the distance between the centers of the pupils of the eyes and the IAD is the distance between the axes of vision of the eyes. These two distances are not identical in general. The experiments indicate that the interocular setting should be based on the IPD and methods for measuring this accurately have been devised.

Temperature errors may arise (1) when the whole instrument is changed uniformly from one temperature to another, (2) where temperatures are constant with time but variable from one part of the instrument to another, and (3) where changes in temperature are taking effect. Effects of the first category, such as changes in lens curvature and lengthening of the optical bar because of uniform temperature variation can be made self-compensating to a considerable extent by careful design.

Chapter 5 deals chiefly with effects of the second and third categories. When the sun shines on the top of a range finder, a temperature stratification takes place in the gas inside the tube, causing a variation in the refractive index of the gas from top to bottom of the instrument. The British have alleviated this effect by stirring the air within the tube. The American solution has been to charge the tubes with helium. Such a solution has created new problems of refocussing and the like as well as problems of charging the tube with helium and of maintaining a high percentage of helium within the instrument. Sections 5.1, 5.2, and 5.3 of Chapter 5 outline the experiments which have led to the solution of the temperature problems as regards stratification of the internal gases in existing instruments. The remainder of Chapter 5 deals with experiments which have led to the development of range finder parts more thermally stable than those in existing instruments.

Chapter 6 discusses the problems of power and base length of ranging instruments. It has been known that increased base length and increased magnification both fail to give the theoretically expected increase in acuity. Certain present experiments confirm these earlier findings in regard to both variables. This experimental work on this problem is by no

means completed and, indeed, our knowledge is not far enough advanced to warrant specific recommendations.

Chapter 7 deals with experiments on calibration of range finders in the field — the expected accuracy, methods of calibration, particularly emphasizing the use of celestial targets and a study of reticle design for the internal adjuster target. Chapter 8 of the report deals with a small number of miscellaneous instrument and operational defects such as pentaprism rotation, use of filters, leveling and alignment errors and the like.

Chapter 4

PERSPECTIVE ERROR

4.1 INTRODUCTION

PERSPECTIVE ERROR is an error due to the fact that the images formed by the objectives do not lie exactly in the planes of the reticles but are removed from the reticle planes by an equal amount for both the right and left sides. Such a condition can be due to any or all of three causes: (1) improper adjustment of the instrument; (2) the use of the instrument at a range other than that used for adjustment; or (3) thermal changes in the instrument which result in expansion of the optical bar, change of focal length of the objectives or curvature of the end reflectors. It leads to a difference in observed range when different interocular settings are used.

The origin of these effects is the fact that light coming from a target through different portions of an objective intersects the reticle plane at slightly different points. This is expected theoretically, and has been demonstrated experimentally by placing stops over the objectives or end-windows in such a way as to expose only a small portion of the window, and observing that the range reading varied with the portion exposed. With the window wide open, the images formed by the different portions are superimposed, and thus a certain degree of blurredness results. With the instrument stopped down, the image is sharper and the range readings correspondingly better. Furthermore, when the instrument is stopped down, the observer uses the area of the optical elements through which the internal adjuster beams pass, and hence the RCS adjustment can be expected to be more reliable than with end-windows unstopped.

4.2 CONTROL BY END-WINDOW STOPS

Early experiments at the Princeton Laboratory at Fort Monroe indicated that the placing of opaque stops over the end-windows of M1 and M2 greatly reduced these perspective error effects. This led, as early as February 1942, to a Report to the Services issued by the Fire Control Section of NDRC. (3) Diaphragms with a 1-inch aperture were placed before the end-windows of the instruments. All studies were made on fixed targets of known range.

Approximately 1,000 readings were taken in these early experiments. It was found that the average of an observer's readings was closer to the true range with the windows stopped down than with them open. This was true for all observers. The improvement is not uniform for all observers, being 20 per cent in the case of the observer who showed least improvement, while in the case of the observer who showed greatest improvement, the errors with the instrument stopped down were only one-sixth as great as with it wide open. A modest reduction in the spread of an observer's readings—a modest increase in the precision with which he makes his settings—was produced by stopping down the instrument. In this regard, one observer showed improvement of 6 per cent, one 12 per cent, while the other three were substantially unchanged. Also, an observer's readings varied less from hour to hour with the instrument stopped down than with it wide open. This was true of four out of the five observers, the improvement ranging from 19 to 39 per cent. One observer showed greater variability by approximately 20 per cent.

The report ends with the following recommendations to the Services: (1) That variable diaphragms, suitable for external attachment to the end-windows, be provided for all existing range and height finders. (2) That range finders now in course of construction be equipped with suitable variable diaphragms. (3) That all observers be instructed to use their instruments stopped down as much as conditions of target illumination will permit. This will be at all hours except a very few minutes at dawn and dusk, and perhaps occasional days of unusually low visibility. Under such conditions of poor illumination the instrument must be used full field to gain sufficient light gathering power.

A report from the National Bureau of Standards discusses these results from a theoretical point of view and points out that perspective errors may be due to a number of other factors. (321)

The Princeton Laboratory at Fort Monroe has given an elementary discussion of perspective error in range finders. (365) This general theory forms the basis of all the experimental work on this topic by the Princeton Laboratory.

Further experiments with end-window stops of 1-inch aperture are reported by the Princeton Labora-

tory at Fort Monroe. (350) The results indicate that the use of a small central part of the height finder optical system for ranging does improve certain characteristics of height finder performance. These experiments are based upon the following theoretical considerations. If there is a suitable kind of differential temperature stratification in a height finder or lack of planarity of end reflectors, then rays passing through different parts of the end-window will be focused on slightly different places in the reticle plane. This may have three effects: (1) a diffusion of the image; (2) a shift of the center of gravity of the image, or (3) a shift of the center of gravity of the whole image relative to the center of gravity of that part of the image using the same part of the end reflector as the internal adjuster image. The effect of the first would be expected to lead to irregular performance, of the second to lead to errors corrected by the internal adjuster, and of the third to both long- and short-term errors uncompensated for by the internal adjuster.

The first experiment studied the magnitude of such errors when a 1-inch aperture was placed in front of the left end-window of a height finder and eccentric stops were placed in sequence in each one of four positions above and below and to each side of the center of the right end-window. The centers of these four eccentric stops were, in each case, ¾ inch from the center of the end-window. The results, for a fixed target at 2,915 yards show variations, for the four positions from 2,869 to 2,926 for one observer and 2,901 to 2,958 for another. Results with concentric 1-inch apertures on both end-windows for fixed targets indicate that: (1) the change in net correction between 2,915 and 4,015 yards was reduced by 30 per cent; (2) the difference between observer's daily means was greatly reduced; (3) the spread within sets of five range readings was reduced about 5 per cent, which is nearly statistically significant for the 5,500 readings involved; and (4) the variability of observers' daily means was not significantly changed.

A second report from the Princeton Laboratory at Fort Monroe deals with reduced apertures employing aerial targets. (359) Full field and 1-inch apertures were employed using 12x and 24x power in both cases. Six standard M1 Height Finders and 17 better and 18 poorer observers were used. The results show that consistency at reduced aperture was found to be much better than at full aperture, using either 24 or 12 power. Precision with 24 power was not twice as good as that with 12 power, which ratio is theoretically expected when the observer's sensitivity is the controlling factor. These findings for aerial targets agree with those already reported for ranges taken on fixed ground targets using reduced power or reduced aperture separately. The improvement in consistency is related directly to the size of the exit pupil, the smaller the exit pupil, the better the performance. Readings of various observers on the same instrument tend to be more nearly the same when exit pupil size is decreased by reduced aperture or increased magnification. During these tests, no calibration adjustments were made on any of the instruments, since the primary purpose was a study of the observer's precision rather than their absolute accuracy. Internal adjuster readings were also eliminated, thus permitting nearly uninterrupted reading of height. All instruments were charged with helium. The weather was clear through the 2-day test. The targets flew crossing courses at about 10,000 feet altitude, with slant range starting at about 14,000 yards, decreasing to about 8,000 yards and then increasing to about 14,000 yards. With 24 power the precision errors were 2.7 UOE for both 1-inch and full aperture. For 12 power the precision errors for full aperture were 4.1 UOE and this was reduced to 3.2 UOE when the reduced aperture was used. Consistency errors were greater for 12 than for 24 power and greater for full aperture than for reduced aperture with either power.

Some observer reactions are given in this report which are of interest. The observers reported difficulty in using a height finder whose eye distance was greatly reduced. Reduction in eye distance takes place when, as in these present tests, the aperture is reduced at the end-window. If the aperture were reduced at or near the objective, the eye distance would be unaffected and the reduction of the aperture should not produce physical discomfort and fatigue. During some informal observations made during a short test at the Naval Gun Factory, the observers reported that they perceived a much greater change in apparent depth for a given change in range with the instruments stopped down. This may be explained if, improved by depth of focus, the reduced aperture reduces the blurring of the image. When one clear and one blurred image are presented with binocular disparity, there is an unconscious tendency to rejudge the blurred image and bring it nearer to the sharp one. Thus, if the target's

image is blurred at full aperture, the reticle should attract the target toward its own depth. Finally, the reduction in aperture reduces the apparent illumination of the image and this fact was noticed by the observers. Each man was asked if the reduction in intensity made it more difficult to use the height finder and they all said that it did not.

Another report from the Princeton Laboratory at Fort Monroe presents further experimental data to support the recommendation that stereoscopic range finders be used at reduced aperture. (364) The report indicates the range errors may occur as a result of instrumental focus errors when the observer's interocular setting or eye position is incorrect. Following a theoretical discussion which shows the perspective effect produced if the target and the images of the reticles are not all in the same plane so that shifting a point of view disaligns the target and corresponding reticle image, the experimental verification is given. Results indicate that the errors intentionally introduced by incorrect interocular settings are much reduced when the 1-inch aperture is placed before the end-windows and still further reduced when the aperture is placed at the objective, when either 12 or 24 power is used. However, the dependence of range on interocular setting varies with the observer and the slope found using a 1-inch stop is of the same order of magnitude as the difference between observers.

These studies are gathered together in a second Report to the Services issued by the Fire Control Section of NDRC. (18) It is pointed out that in an ideal stereoscopic range finder the target images formed by the right- and left-hand objectives would lie accurately in the planes of the right- and left-hand reticles. In an actual instrument they are not there for various reasons, the principal ones being: (1) imperfections in adjustment of the objective and reticle during assembly; (2) temperature changes in the optical bar, which alter the distance of the reticle from the objective, and in the objective itself which alters its focal length; (3) the fact that, even if the instrument were perfectly adjusted for one target distance, the images of targets at other distances would not be on the reticle plane.

It has been found by these studies reported that no errors result if the interocular distance is correctly set and the two sides of the instrument are accurately matched, i.e., if the distances of the target images from their reticle planes are equal in both size and sense. If the two sides of the instrument are not matched, lateral head movements will cause range errors. Whether or not the two sides of the instrument are matched, range errors will occur unless the correct interocular distance is set into the instrument. Under controlled conditions, errors as large as 30 UOE have been observed in using the Army M1 Height Finder when an improper interocular setting was put into the instrument. It is believed on both theoretical and experimental grounds that perspective errors of 5 to 20 UOE may be common under service conditions with virtually all types of precision stereoscopic range finders. Such errors can be materially alleviated by reducing the size of the exit pupil. This is most conveniently done by means of diaphragms located near the objectives or the end-windows. The better location is near the objectives.

4.2.1 Recommendation of Variable Diaphragms

A previous Report to the Services had already recommended that all range finders be provided with variable diaphragms and that observers be instructed to use the instruments stopped down as much as the conditions of external illumination will permit. (3) In the second report, this recommendation is again reported with the additional observation that, in new instruments the diaphragm should be located near the objective. Diaphragms placed at the end-windows are not quite so satisfactory, but because of ease of attachment may be preferable in the case of instruments already in the field. Fixed stops are not recommended because the full light-gathering power of the instrument may be required in some important tactical situations.

In another previous Report to the Services, attention was drawn, on other grounds, to the importance of correct interocular settings. (9) This is again emphasized. It is now recommended that an accuracy requirement of 0.25 mm be placed upon the interocular adjustment mechanism, and that it be required to be self-locking. It is also recommended that care be exercised in keeping the objectives in proper focal adjustment. In particular, in helium-filled instruments it is desirable to readjust the objectives when helium is adopted, and thereafter to maintain the helium content at such a level that the adjust-

ment is not impaired. The Report ends with a section on the theory of perspective errors.

4.2.2 Detailed Studies of End-Window Stops

Detailed reports of these studies will be found in several Fort Monroe Princeton Laboratory studies. In the first of these reports the findings were as follows. (512) Definite improvement due to the use of end-window stops was found because: (1) variability of the median of five range readings is reduced, the probable error being cut about 30 per cent; (2) observer differences are both smaller and less variable; (3) observer net correction is reduced for each of five observers; and (4) the mean Curve B of several student observers was improved by 30 per cent. Probable improvement was found for differences in observers' means for the same day which were probably reduced by the use of stops. No significant improvement was discovered when stops were used for variability of daily means, and variability within sets of five readings was changed probably less than 10 per cent.

Another Princeton Laboratory report is concerned with the interaction between dependence of range on eccentric stops and internal adjuster readings. (514) It was found that the range read by a height finder stopped down to 1-inch aperture depends on the location of the aperture over the end-window. It was established that (1) the effect due to horizontal displacement depends on the internal adjuster reading and (2) the position of the RCS wedges is not responsible for this effect, either in helium or in nitrogen. The cause of this effect is probably thermal in origin.

Another Princeton Laboratory report discusses the locations of stops in the M1 Height Finder. (516) It considers the effect of stops which are at or before the objective and gives a theoretical discussion of the possible positions at which such stops might be placed in the M1 Height Finder system and of the location and diameter of the stop images.

The point of view from two circular stops is discussed theoretically in another Princeton Laboratory report. (519) The report shows that the point of view of an optical system limited by two circular stops is, laterally, very nearly halfway between the sides of the useful bolt of light.

Finally a Princeton Laboratory study discusses perspective error in ortho-pseudo-stereoscopic range finders of the Mihalyi type. (526) This is again a theoretical study. The analysis shows that, with incorrect interocular setting or head shift in such an instrument, no perspective error may be expected with change of range to target, or symmetric defocusing between target and beam splitters, including symmetric defocusing of objectives or defocusing between joiners and the eyes. No effect will be apparent for incorrect ocular setting when there is a symmetric defocusing between target and splitters but, with head movement, double the effect will be expected over that found in an ordinary stereoscopic range finder. A perspective error may be expected for both incorrect interocular setting and shift of head when defocusing exists between splitters and joiners.

A report from the Frankford Arsenal, Princeton Branch, deals with designs of internal stops for height finders. (235) It is proposed to equip the M1 Height Finders, at the objectives, with externally operated, removable diaphragms. It is pointed out that a continuously adjustable iris diaphragm is not necessary; a simple "in and out" diaphragm with single-size stop would be satisfactory. The problem falls into two parts which may or may not be satisfied by a single solution: (1) the design and construction of objective stops to be installed in height finders during production, and (2) the design and construction of objective stops to be installed in height finders already built and perhaps in the field. A continuously adjustable iris diaphragm stop devised by the Eastman Kodak Company is considered satisfactory but perhaps needlessly elaborate for the solution of the first problem. The report suggests a simple type of diaphragm and outlines steps for further development.

Many of these matters are taken account of in a modification of a special M1 Height Finder for experimental purposes reported by the Frankford Arsenal, Princeton Branch. (237) In order to reduce or study perspective error, the following modifications were to be introduced:

1. Focusable objectives so arranged that their displacement in and out of the optical bar is controlled from outside the instrument with a satisfactory degree of precision and the amount of shift indicated on some form of scale.

2. Special reticles, modified by cementing small plane-parallel pieces of glass over the end reticle

marks in such a way that the focus of the images of these reticle marks, as seen at the ocular, will differ by approximately ½ diopter from the focus of the other reticle marks.

3. A modified interpupillary scale on which readings of the position of the interpupillary adjustment could be made down to 1/20 of a millimeter.

4. A new interpupillary adjustment sufficiently precise and free from backlash to obtain satisfactorily a tolerance of 1/20 mm.

5. Diopter scales graduated at intervals of 1/10 diopter.

6. Installation of the latest type of controlled apertures.

7. Fitting of the height-adjustment knob with a graduated scale.

Unified field modifications of the M1 Height Finder are proposed in a Princeton Branch report of the Frankford Arsenal. (247) These include an eye positioner by improvement of the present eye shields. The use of diaphragms had already been authorized by the Army.

It will be noted that the use of diaphragms is merely a measure for reducing the effect of perspective error in range finders. It by no means eliminates the causes of this error. Attempts at eliminating or reducing the causes of this error will be discussed in subsequent sections of this summary of experimental and theoretical work on range finders.

4.3 THE QUESTION OF THE INTEROCULAR SETTING

Quite early in the NDRC study of stereoscopic range finders, it became evident that setting the exactly correct interocular measure between the two eyepieces was a critical matter. In the Tufts College Laboratory of Sensory Psychology and Physiology variations in the interpupillary setting of a Navy Mark 2 Stereo Trainer were made for three observers, with the following extremes for the different subjects: 62-68 mm; 65-69 mm; and 61-64 mm. (556) In all three cases it was found that a linear relation existed between the magnitude of the constant error and the interpupillary distance set into the instrument. For the extreme settings, the differences of the constant errors for the three observers were respectively 8, 6, and 4 UOE. The constant errors were invariably large and negative (i.e. ranges read too short) when the interocular distance was too narrow, and smaller and positive (i.e. ranges read too long) when the interpupillary setting was too wide.

Independently, similar observations were made at the Harvard Fatigue Laboratory, employing six observers on the Harvard Fatigue Laboratory stereo acuity instrument. (265) Interocular distance was varied in both directions, approximately 5 mm on either side of the normal interpupillary distance, to the point where the observer could no longer fuse the reticles. The investigators were interested in variability of judgment rather than accuracy of ranging. The differences in interpupillary distance gave no constant trend in variability of observation for two of the six observers. For the other four observers, the results indicate that there is an optimum value of interocular setting which gives the smallest amount of variability. When this optimum setting is violated in either direction, there is a resultant increase in variability which becomes progressively greater as the amount of violation is increased. For two observers, this increase in precision was considerably more marked for settings of the instrument narrower than the measured interocular distance; in one case giving a decreased precision of approximately 20 seconds of arc, and for the other approximately 23 seconds of arc, for the extreme narrow settings.

4.3.1 Effect of Interpupillary Adjustment

It was noted in this study that the optimal precision did not occur exactly at the measured interpupillary distance for any one of the four observers. There is apparently a preferred setting which was narrower than the measured setting for one observer, and wider for the other three observers. These differences between the measured interpupillary distance and the preferred interpupillary distance were relatively small—being 1 mm in three cases and 2 mm for the fourth observer. Such distances were substantially found to be of considerable importance. The investigators believe that they may be due either to the fact that the best interocular distance differs from the interpupillary distance, or to errors in measuring the interpupillary distance. However, existing methods of measuring interpupillary distance are subject to errors of as much as 1 or 2 mm. All such methods assume that the lines of sight are maintained in a parallel position with fixation at infinity. Movements

of convergence from this position are normal and usual while movements of divergence are infrequent, if they ever occur in the normal individual. Hence if any eye movement occurred during the measurement of the interpupillary distance, the measured value would tend to be narrower than the true value.

These results are recorded in a Report to the Services from Section D-2, NDRC. (9) This report makes the following recommendations: that it is important (a) to exercise extreme care in obtaining the correct measurement of the interpupillary distance of each height or range finder operator before he begins his training; and (b) to set this measured distance carefully into the range finder.

How important this correct interpupillary adjustment may be is pointed out in several analyses made by the Princeton Laboratory at Fort Monroe. In a theoretical study of the M1 Height Finder it is pointed out that the detailed behavior of a stereoscopic range finder may be efficiently and simply analyzed in terms of points of view and reticle images. (515) This is done by imaging the reticles into the target space, and by analyzing the cases when two objects, or an object and a reticle, are seen in monocular alignment. The points of view, or the points of perspective, from which the judgments of alignment seem to be made, are found to be the centers of the entrance pupils of the system. An additional theoretical study (518) shows the change of separation of the points of view of an M1 Height Finder as interocular setting is varied for three sizes of observer's pupil and for full and 1-inch aperture stop on the end-windows. It is emphasized that the edge of the pupil of the observer acts as a second stop and hence centering of the pupil of the observer to the exit pupil of the instrument must be exact if the freedom of movement is not to be constricted.

The Princeton Laboratory at Fort Monroe also reported an experimental study on the effect of interocular setting changes on range and RCS settings. (521) Two expert observers were used. Test was made with a standard M1 Height Finder at nine interocular settings, with 12 and 24 powers and with three end-window stop conditions from full to 1-inch aperture. It was found that change of interocular setting produces a proportional change in range reading of considerable magnitude. The amount of shift is reduced to one-sixth with 24x magnification, or to one-third with 12x by a 1-inch stop either at the end-window or at the objective.

Tufts College also reported another experiment on effects of interocular settings on ranging errors. (561) These experiments were again made with the Navy Mark 2 Stereo Trainer and show that constant error is a linear function of the inter-eyepiece distance separation used. An error of 1 mm in the setting of the scale of the instrument produced a change in constant error of ranges of from 1 to 2 UOE. These errors are negative when the separation is too small and positive when the separations are too large. In the report is also the description of a device for measuring inter-eyepiece distance which was not further developed. A table of measurements of 10 subjects using a millimeter rule, the Shuron apparatus, the Navy Trainer, and this new apparatus shows decreasing variability in that order.

The preliminary observations noted above led to a serious study of interocular adjustments in stereoscopic range finders and their effects. The reports on this subject are discussed in a Report to the Services issued by the Fire Control Section of NDRC to which the reports of original studies are attached as supporting evidence. (38)

It had already been pointed out in a Report to the Services (18) that serious range errors can occur unless the distance between the oculars of the range finder accurately corresponds to the interpupillary distance of the observer. The errors in question can be very materially reduced by the use of suitable diaphragms and by care in maintaining the focal adjustment of the objectives. In this report it was recommended, so far as the present problem is concerned, that an accuracy requirement of 0.25 mm be placed upon the interocular adjustment mechanism and that it be required to be self-locking. Also it was noted that no entirely satisfactory means for measuring the observer's interpupillary distance was then available and that NDRC was in process of developing such a measuring instrument.

This instrument was developed by the Harvard Fatigue Laboratory and is described in the report. (282) This new instrument consisted of a plane mirror at a distance of 33 cm before the subject's eyes. Two stadia wires were mounted 3.5 cm in front of the mirror on the graduated limb of a microscope stage. The lateral separation between the two wires was adjusted by the observer. The position of the right wire was controlled by a coarse rack-and-pinion adjustment, that of the left wire independently by a fine adjustment. The observer's head was steadied by a Bausch and Lomb head support. In operation, the observer fixated with one eye the reflected image

of that eye and then moved the proper stadia wire until it appeared to bisect the reflected image of the observed pupil. This procedure was repeated for the other eye. When the observer had checked his settings for each eye and was satisfied with the adjustments, the distance separating the two stadia wires was read from the scale and vernier to determine the interpupillary distance.

The report also contains a discussion of the possible sources of error of this and other available instruments for measuring the interpupillary distance. Experiments were completed using the Zeiss Gauge, the Shuron Gauge, the Shuron Gauge with mirrored image, the Bausch and Lomb Gauge, and the new instrument. Only the new Harvard instrument and the Bausch and Lomb Duplex P.D. Gauge provide measurements of sufficient reliability for the purpose at hand. Both of these give sufficiently accurate and repeatable readings. However, their readings do not agree, and it has been necessary to determine which, if either, measures the optimum distance to set into a range finder.

4.3.2 Measurement of Interaxial Distance

During the Harvard experiments (282), while measuring IPD with the mirror and stadia instrument, the observers frequently reported parallax between the stadia wires and their reflected images. These reports are noteworthy because the parallax was perceived when the real wires appeared to bisect the observer's pupils. This state of affairs suggested that the observer's external lines of sight did not pierce the geometrical centers of their natural pupils. The suggestion seemed important because, if true, it meant that IPD is an inaccurate measure of the distance separating corresponding lines of sight in the two eyes. Practically all of a number of observers, both experienced and naive, noted the differential effect in varying degrees. Hence the Harvard group began to make a new set of measurements, namely the separation between the stadia when the parallax between each wire and its reflected image was reduced to zero. This measurement was called *interaxial distance* [IAD] and presumably measures the distance between the two principal visual axes of the eyes.

For four skilled observers the difference between the IPD and the IAD ranges from 0.06 to 0.77 mm and in three of the four cases the IAD was larger. For 14 other subjects the IAD was larger in ten cases, IPD larger in two cases, and not significantly different in the remaining two subjects. These observations could be repeated with only very slight variability.

A study of IPD and IAD separations was then made by the Harvard Group on 24 enlisted men of the Coast Artillery Antiaircraft Battalion 605, Battery C. The mean variation for each set of readings was, on the average, of the order of 0.2 mm. The average IAD value for the group was 65.07 mm. Thus, the difference between the IAD and the IPD of the group measured with the same instrument was 0.85 mm. Very few of the subjects gave the same values for both measurements. Nearly all of the subjects had the IAD greater than the IPD. The similar testing of 105 servicemen at Camp Davis gave similar results. In both groups extreme cases were found in which the IAD was 4 mm larger than the IPD. These results support the hypothesis that the IAD does not equal the IPD in observers with normal vision in most cases. In other words, the principal visual axis of the eyes seldom corresponds to the geometrical center of the pupil but is usually found on the temporal side of these points.

As a result of these findings the Bureau of Naval Ordnance contracted with the American Cyanamid Company to construct several experimental models of the IAD gauge which was named the interaxialometer. The completed instruments gave determinations with excellent precision and consistency.

The Harvard Group then made a study of the properties of the interaxial distance. They found that the measured IAD values were very nearly the same for each of four accommodated distances varying from 33 cm to infinity and that IAD remains constant for verged distances from 0 to 8 degrees or uncontrolled vergence. Although there is a considerable difference in IPD with lateral rotation of the eyes, none was found for IAD under these conditions or for vertical rotary eye movements or vertical rotary head movements. On the basis of these results, the investigators present the hypothesis that within wide limits each human eye may be treated as if it possesses but one perspective center, whether the eye is stationary or moving, and that this center lies in the vicinity of the center of rotation of the eye. The practical significance of this idea is that it permits the eye to rotate through a wide angle without occasioning a perceptible amount of parallax between any two fixed sights. The measurements demonstrated that when the eyes are rotated through angles of

±8 degrees, the distance separating corresponding lines of sight in the two eyes was constant.

The Harvard report contains a description of a self-locking interocular device for controlling the separation between eyepieces in the M1 Height Finder and the Mark 42 Range Finder. This idea was adopted by the Services and is important because it was discovered, in the previous non-locking arrangement, that with wear there was a tendency for the eyepieces to spread when the operator pressed his eyes into the eyecups. The report also outlines the method to be employed for calibrations of the axialometer.

In the final section of the Harvard report, the results of experiments are given to indicate whether IPD or IAD, if either, should be used to separate the oculars in balanced stereoscopic range finders. The indication seems fairly clear and conclusive. Perspective parallax occurred when the lines of sight of the oculars were separated by the IPD of observers whose IPD was not equal to their IAD. The amount of this perspective parallax, by measurement, was found to be proportional to the difference between the IPD and the IAD of the observer. When the oculars were separated by an amount equal to the observer's IAD, on the other hand, perspective parallax was eliminated. The use of reduced apertures is another method for minimizing the effects of perspective parallax in stereoscopic range instruments and experimental results are presented to demonstrate that when the exit pupils of the instrument are smaller than the natural pupils, the observer's lines of sight can in effect be made to coincide and move with the lines of sight of the instrument. Parallactic errors produced by asymmetrical "clipping" are emphasized when the instrument is stopped down and it is believed that the likelihood of occurrence of these "clipping" errors should be alleviated by separating the reduced exit pupils by a distance equal to the observer's IPD.

Incidental to a Navy Bureau of Ordnance report on the effects of helium charging on range accuracy, it is pointed out that such accuracy, with improper interpupillary settings in air and in helium, are of such magnitude as to obscure the actual effects of helium which are considerable. (318)

4.3.3 Effect of Perspective Error

A study of the effects of interocular setting of range finders having perspective error is reported by the Bausch and Lomb Optical Company. (107) Settings for interocular distance were used with the instrument full open or stopped down. The interocular distance was varied systematically in an effort to determine whether or not the optimal ranging results most closely approximated the IPD or the IAD measurements. In this investigation an improper adjustment of a known amount was deliberately introduced into a Mark 58 Range Finder which viewed through an indoor collimator. Four expert observers were used. The results of one observer showed the interaxial distance to be the correct setting. Two other observers show a setting which is neither the interaxial distance nor the interpupillary distance, but is closer to the former. The interaxial distance of a fourth observer was not known. It will also be noted that for the first three observers the IAD was narrower than the IPD, which is contrary to the average situation as found in the measurement of these distances in a considerable number of individuals by the Harvard group. The relation of these results to theory is considered. In conclusion it is pointed out that the unavoidable sources of error are small enough to make an exact choice of the interocular setting of secondary importance. This, however, is by no means true of an instrument that is not properly adjusted. The specifications as usually written now permit a misadjustment for perspective error of 0.2 of a diopter. In view of the findings of this experiment it is obvious that this is a much larger error than should be tolerated. Since it is not a particularly difficult adjustment to make, it is highly desirable to specify that all range finders should be adjusted to eliminate perspective error for some prescribed object distance for the main system. A similar adjustment should be required for the internal adjuster system.

Some experimental results are reported from Camp Davis through Brown University using an M1 Height Finder. (150) The target was a telephone pole at 1,700 yards. Ten observers of a stereoscopic observers' class were used as subjects. Three subjects had a difference of 0.25 mm between their IAD and IPD, three a difference of 0.5 mm, and four a difference of 0.75 mm. The results indicate, in terms of these differences, that for this group of men change in consistency was not related to the amount of difference between the interaxial and interpupillary distance.

Brown University made a report which is also included in this material reported to the Services.

(149) Because it had been shown that it is necessary that the range finder observer adjust the separation of the oculars on the instrument so that the distance between the two exit pupils is exactly the same as his interocular distance, and because it was discovered that the interpupillary distance scales mounted on the height and range finder eyepiece assembly are not sufficiently accurate to guarantee a precise setting of the separation of the two exit pupils, some other method had to be employed. This memorandum describes the construction of a template for use in making precise settings of ocular separation once the observer knows his interocular distance. The template is easy to construct and should be provided for each observer. If the observer uses the template in the manner described in the report, he can adjust the exit pupil separation on the range finder so that it is not in error by more than 0.25 mm. The template consists merely of a strip of hot rolled steel. Two small holes are drilled exactly the desired interpupillary distance separating their two centers. In each case the size of the holes exactly corresponds to the size of the exit pupil of the instrument. The exact interpupillary separation to 0.25 mm is stamped on each template. The holes are covered with tissue paper.

The method of using the template is: (1) focus both eyepieces to the same value; (2) point the instrument to a bright part of the sky or to the moon at night; (3) have an assistant narrow down the separation of the oculars to some value about 2 mm below the observer's interocular distance. Then have him widen the separation by 0.25 mm steps according to the marks on the instrument scale, stopping as soon as the two exit pupils are seen exactly centered in the two holes of the template. The settings should always be started at less than the interocular distance to minimize the backlash error. If end-window stops are being used instead of the full-field instrument, the instrument should be set for range and the measuring scale adjusted to read 5,000 yards before making observations of the exit pupil separation.

4.3.4 Recommendations

On the basis of this considerable mass of data the following summary and recommendations are made in the covering Report to the Services. (38)

1. When the exit pupils are very small (about 1 mm) the errors due to errors of interocular setting are negligible.

2. As the exit pupils are made larger, the error gradually increases, reaching its maximum value when the exit pupil is about the size of the pupil of the observer's eye.

3. When the exit pupil is larger than the pupil of the observer's eye, the error is independent of the size of the exit pupil. In some cases it has been found to reach its theoretical value, but in the careful study at Bausch and Lomb the theoretical value was approached only at low magnifications. No explanation has been found for this apparent dependence of perspective error on magnification.

4. The interocular setting which gives zero perspective error is not critical with small exit pupils. With large exit pupils it is critical and, in the case of some observers at least, equal to the interaxial rather than the interpupillary separation. But even under carefully controlled conditions there are other factors which affect the true range reading fully as much as the difference between interaxial and interpupillary distance; e.g., if the target is not kept in the same position of the field in which the internal adjuster target was set systematic errors may be introduced which will completely mask those due to a moderate amount of interocular maladjustment. The operator cannot be expected to use interpupillary distance under some conditions and interaxial separation under other conditions. Therefore some sort of a compromise must be effected.

In view of all these considerations, it seems evident that the elimination of perspective errors is a matter of extreme difficulty if exit pupils larger than the pupil of the eye are used. Therefore the instruments should be stopped down wherever possible. In this stopped-down condition, the oculars should be set to the interpupillary distance, since maximum head freedom is thus achieved. In conditions of dim light, it will be necessary to remove the stops in order to gain light-gathering power. It may also be necessary to get additional head freedom by increasing the exit pupil size, in the Naval situation, when a ship is rolling badly. But under either of these conditions it will be impossible to obtain ranges of high precision, no matter what interocular setting is used. Presumably the interaxial setting would be the optimum, but in the presence of other large sources of error the gain to be expected is not great enough to warrant the adoption of a special practice. Hence it should be concluded that the interpupillary distance should be used in all cases.

This reasoning leads to the following recom-

mendations made to the Services. (1) The observer's interpupillary distance should be measured by means of the Bausch and Lomb Duplex P.D. Gauge, or its equivalent, and this distance should be set into the oculars at all times. (2) For instruments whose interocular scales cannot be trusted, the oculars should be set by means of templates described above. This procedure should, however, be regarded only as a stopgap until such time as the more accurate interocular mechanisms described in the previous NDRC Report to the Services (18) are available. These recommendations should emphasize that the instrument should be stopped down whenever operating conditions permit.

The Applied Psychology Panel subsequently reported two direct methods of putting the correct interocular setting into the range finding instruments, avoiding the use of a template or interpupillometer which involves special equipment. (75) Neither method proved to be either accurate or reliable. It is recommended that adequate interpupillometers for measurement of interpupillary distance and templates for each observer be provided for use in setting the oculars of all height and range finders.

A final report on this topic was made by the Applied Psychology Panel regarding the precision of setting the oculars of the range finder with interpupillary distance templates of different design. (78) This is an adjustable template developed by the Naval Bureau of Ordnance which is described in the report. This report describes ten settings of the ocular of a range finder by each of 10 students at the Fort Lauderdale Naval Training School, Fire Controlmen (R) with the Bureau of Ordnance template and holder. Five of these settings were made with a reticle pattern consisting of two pairs of vertical parallel lines in the template. The other five settings were made with a reticle pattern consisting of two small circles. In addition, these men made five settings of the range finder oculars with their own personal NDRC templates.

It was found that there was no statistically significant difference in the precision of setting the ocular separation between any of the three template conditions. In all cases, the precision of the settings was better than 0.25 mm. However, the Bureau of Ordnance variable template has advantages over the NDRC fixed template in that it is more convenient and allows a quicker adjustment; its holder places its reticles in the plane of most distinct focus of the light emerging from the exit pupils; and it can be made suitable for any range finder operator, thus avoiding the necessity of each operator's having his personal template available at all times. It was also found that the circle reticle pattern has the disadvantage with some range finders of having the small circles off-center along the vertical axis of the exit pupils. The parallel line reticle does not have this disadvantage. The holder provided fits the template to the oculars of Range Finders Mark 42, models 4 to 6 and 8 to 13 only. However the Bureau of Ordnance templates can be used on other range finders without the holder. When this is done, the same procedure should be used as that developed for the use of the NDRC template noted above. The use of this type of template and the development of holders for other types of range finder is recommended.

A Frankford Arsenal Princeton Branch report presents specifications and outlines a design for an instrument to be incorporated in the M1 Height Finder and to be used for measuring the distance between the exit pupils of the instrument with an error of less than 0.1 mm. (230) The instrument is also to be used for setting precisely a prescribed distance between the exit pupils, such as the observer's interpupillary distance. Such an interpupillometer consists of two concentrically marked, translucent reticles so mounted in the plane of the exit pupils, with a reticle in front of each exit pupil, that each reticle may be moved in the plane of the eyepiece assembly plate, both parallel and perpendicular to the axis of the height finder. When the reticles are so adjusted that each exit pupil is concentric with the concentric markings of its reticle, the distance between the exit pupil centers may be read from a calibrated micrometer which provides and measures the movement between the reticles in the direction of the height finder axis.

Chapter 5

TEMPERATURE EFFECTS

5.1 THERMAL EFFECTS IN COINCIDENCE RANGE FINDERS

The British discovered late in the 30's that range finders tend to develop errors on elevation that are not present prior to elevation. The errors revealed appear to be quite definite, but no systematic investigation had been carried out under Service conditions and the atmospheric conditions most favorable to the development of these errors were not known. Towards the end of 1938 the Admiralty Research Laboratory [ARL] decided to investigate the problem and hence apparatus was designed which would enable the errors of range finders mounted in the open to be examined at any time during the day or night, at any angle of elevation, and without the necessity of utilizing any external object to serve as a ranging mark. Furthermore, the British found that wartime experience of the results of antiaircraft gunnery provided its quota of evidence that range finders tend to read low on elevation and ARL was asked in 1939 to investigate the problem without waiting for the delivery of precise testing apparatus. At this time the daily variation of the coincidence adjustment at zero angle of elevation of two Type F.Q. 25 range finders had been under investigation at ARL. Hence it was decided to prepare a number of reflecting windows and to use them immediately in conjunction with these two range finders. The first report from ARL deals with these findings. (56)

Before this time it had not been practicable for two reasons to make use of the sun as a ranging mark. In the first place, there is the risk of damage to the eye of the observer, and although this objection can be met by providing a dense neutral filter over the eyepiece, such filters would be likely to crack owing to the concentration of heat in this position. A far more serious objection lies in the fact that the whole of the heat transmitted into the instrument is available for disturbing various balsamed surfaces and, more particularly, for upsetting the general thermal conditions previously existing in the instrument. It appeared that these objections could be met by mounting partially reflecting plane parallel windows directly in front of the existing height finder windows. The metallic deposit on these additional windows would reflect back all the heat likely to create disturbing temperature gradients within the instrument, and by suitably controlling the density of the deposit, sufficient light might be transmitted to permit a clear view of the sun. A number of these reflecting windows were accordingly made, checked for plane parallelism, and were used throughout the tests whenever observations at the elevation of the sun were required. They were satisfactory for this experimental purpose and proved that a transmission of 0.006 per cent of the light was acceptable.

Experiments involving systematic observations of elevation error were carried on both by day and night. By day, the ranging marks employed were the sun and moon whenever available, together with a church spire of known range to give the error at zero angle of elevation. By night the stars and moon were used as targets. At first ARL personnel acted as observers but subsequently six Service range takers were made available for this purpose.

The standard procedure was to obtain sets of values of the error at various angles of elevation and at approximately hourly intervals during the complete period of 24 hours. Internal adjuster readings were obtained for each set of readings. A single reading in the report is the mean of ten separate observations of the error expressed in seconds in the object space. During months prior to the experiment, Barr and Stroud had been fitting internal temperature tubes to new deliveries of range finders of Type F.Q. 25. The laboratory investigation was therefore directed in its initial stages to an examination of the error to be found in instruments both with and without these tubes.

A study of the results leads to the following conclusions. (1) The reflecting windows proved satisfactory in that their use does not modify in any way the previously existing error of the range finder. Hence the safe use of such windows for a field check of the coincidence adjustment on the basis of solar observations seems confirmed. (2) Elevation errors are not constant in amount throughout the day, but exhibit a very marked tendency to disappear in the region of 6 a.m. to 8 a.m. and again between 5 p.m. and 7 p.m. On the other hand, they tend to rise to a maximum between 11 a.m. and 1 p.m., and between

10 p.m. and midnight. These hours, it is stated, are only approximate and, no doubt, in any particular case they will be closely connected with the variation of external temperature, and the incidence of direct radiation from the sun, throughout the day. There is evidence that the periods of zero error occur roughly 2 hours after the times of stationary external temperature; those of maximum error, 2 hours or so after those times at which the rate of change of external temperature is greatest. (3) Elevation errors are invariably negative, i.e. the instrument if adjusted correctly at zero elevation reads low at higher elevations. For the F.Q. 25 type of range finder it was found that the maximum elevation error may be considerable and at times errors amounting to 13 seconds of arc were shown. (4) It was also found that the presence of internal temperature tubes gives limited improved performance.

5.1.1 Temperature Tubes and Air-Stirring

The investigators suspected that the cause of the elevation was to be found in the presence, in the air within the tube of the range finder, of certain temperature gradients which themselves give rise to deviations in the path of the light. In other words, radiant heat from the sun on the top of the tube would set up temperature stratification of the air within the tube of the instrument. A positive vertical temperature gradient within the tube would produce a systematic tendency to low readings at the higher elevation. Such gradients, no doubt, can be very small and might be difficult to record experimentally. It should be remembered, however, that the total light path within the range finder investigated is of the order of 18 feet, and it may well be the case that the cumulative effect of these small gradients over such a comparatively long distance may be appreciable when reduced to seconds. The introduction by Barr and Stroud of internal temperature tubes which, it was hoped, would promote temperature equalization, was based on this theory of the origin of the error. These tubes have met with a measure of success at times. At other times, however, and particularly by day, the residual error after fitting with internal tubes is by no means negligible. For example, in one case, an instrument so filled revealed an error on the sun of 9.8 seconds at an elevation of 50 degrees.

Because the temperature tubes did not give complete satisfaction in eliminating elevation errors other solutions were considered. It is not improbable that the substitution of internal vacuum tubes for the existing temperature tubes would yield some improvement in performance. A comparatively low vacuum should suffice for this purpose, but such a modification could not readily be adapted to existing instruments in Service. Therefore it was decided to experiment with a simpler solution and one which, if successful, could be rapidly fitted. The effort was made to equalize temperatures along the light path between the end penta prisms and the object glasses carried by the inner frame by a vigorous mechanical stirring of the inner air. With this end in view, a simple reciprocating hand pump was fitted to the range finder in such a way that the internal air was agitated but no fresh air from the atmosphere was introduced at any stage into the range finder. With such a closed system, no dust, moist external air, or air at a temperature sensibly different from that within the instrument can enter. Experimental stirring seems to remove the elevation error almost entirely. Replacing the hand pump with a motor-driven pump indicated that continuously circulating air, as distinct from the type of air surges realized with the hand pump, was equally effective in removing the elevation error to a considerable extent. It was determined that such air circulation did not produce an optical shimmer which would affect operator's consistency of readings. Averages of elevation errors of the range finder are: without internal tubes and with no air stirring, −7.6 seconds (range: −4.0 to −13.3 seconds); with internal tubes, −4.0 seconds (range: +2.7 to −1.10 seconds) and without tubes but with stirring, −0.3 seconds (range: +2.3 to −3.4 seconds). The elevation errors of the internal adjuster were: without tubes or air stirring +5.7 seconds (range: +10.6 to +0.5 seconds); with internal tubes −0.2 seconds (range: +7.3 to −6.0 seconds) and without tubes but with stirring −0.4 seconds (range: +4.0 to −3.4 seconds). Hence these results show that the introduction of internal temperature tubes reduces the mean elevation error of the range finder from about −7.5 seconds to −4 seconds. The method of stirring, however, substantially eliminates the error, the small residual being less, on the average, than 1 second.

For the stirring procedure, it was realized that, on stopping the pump, the error would reestablish itself in course of time. When the original experiments

were carried out on the sun it was noticed that, as soon as pumping was stopped, the coincidence cut broke continuously at such a rate that it became impossible for the observer to maintain the cut during this period. Hence a continuous photographic record of the appearance of the cut was taken. Before the stirring commenced the mean error was −10 seconds, but within 7 seconds of the hand pump being started the error had changed to +1 second at which value it remained during the remainder of the stirring. On stopping the pump the error remained steady for about 10 seconds, after which a further change, occupying 10 seconds of time, to +5 seconds of arc took place, followed gradually by the return, after a further 20 seconds to its original value before stirring commenced. Thus the error was largely eliminated very quickly after pumping was commenced but returned to its maximum value within 40 seconds of stopping of the pump. No explanation was advanced for the temporary alteration in the error, amounting to +4 seconds, which occurred 20 seconds after pumping was stopped.

Similar experiments were carried on and simultaneously reported by ARL on the elevation errors of range finders Types U.D. 4 and U.K. 4. (55) The findings substantiated those already outlined above for the Army instrument, Type F.Q. 25 for this Navy instrument. It was found that the elevation error is not constant but varies rhythmically throughout the day, rising to a flat maximum around 1000 to 1600 hours. In all cases, the elevation error tends to indicate low ranges. The maximum error observed was 11 seconds in an instrument with base length of 15 feet, hence an error of this magnitude corresponds to a range error of 275 yards at 5,000 yards.

The U.D. 4 instrument is normally provided with two desiccating tubes leading outwards to the respective ends of the range finder from two connections near the eyepiece. With a view to facilitating any instrumental modification which ships might be called upon to undertake, it was first decided to make use of these existing tubes for stirring the interval air. Such an arrangement made little impression on the elevation error and the desiccating tubes proved to have leakages. Hence new holes were provided in the range finder in a way described in the text. Such stirring of air substantially reduced the elevation errors in U.D. 4 but not to the same extent as with the F.Q. 25 instrument. This is probably due to differences in design and, it will be remembered, that the improvised stirring relates only to the space between the two ends of the inner frame and the end reflectors. It is possible, therefore, that the small residual errors not removed by the fitted jet tubes may be attributed to temperature gradients within the inner frame. Also, the investigators point out that small residual mechanical bending effects should not be overlooked. For this instrument the mean elevation error at 30 to 40 degrees elevation was standard: −4.9 seconds (range: −3 to −11 seconds); fitted with jet tubes: −1.3 seconds (range: +1 to −4 seconds). However, the weather was cooler and more unsettled during these tests than during those for F.Q. 25, with the result that no large errors were developed in the instrument in its standard condition. Results show that the 12-foot U.K. 4 Range Finder is susceptible to elevation errors of the same order of magnitude as the longer 15-foot U.D. 4 instrument and again that internal stirring effects a considerable improvement in performance in this respect.

During the autumn and early winter of 1940, ARL made a further comparative study of the elevation errors of the Goerz Range Finder No. 8 and the Barr and Stroud No. 10 instrument by the same experimental methods. (57) These experiments were carried on in October and November when the British weather is cool and more even temperatures may be expected. It was found that during this autumn period the average elevation error of the Goerz instrument was about three times that of the Barr and Stroud, the latter being about one-half that obtained with the same instrument during the summer period reported above. Internal stirring of the air reduced the mean elevation error of the Goerz instrument from −3.9 seconds (range: +1.1 to −9.6 seconds) to −1.7 seconds (range: +2.6 to −5.1 seconds) and for the Barr and Stroud from −1.1 seconds (range: +0.7 to −3.9 seconds) to +0.5 seconds (range: +2.8 to −3.2 seconds).

Finally, during this period, ARL investigated the elevation errors of Army Range Finder No. 3 Type U.B. 7. (58) The mean altitude of the sun during these trials was only 31 to 38 degrees. When not fitted with internal temperature tubes and with no air stirring the mean elevation error was −4.6 seconds (range: −2.0 to −8.4 seconds); with air stirring but with temperature tubes removed −1.5 seconds (range: +2.2 to −5.3 seconds) and fitted with temperature tubes −1.2 seconds (range: +1.9 to

−7.1 seconds). The investigators conclude from these results that: (1) The fitting of internal temperature tubes reduces previously existing elevation errors by about one-half. (2) Air disturbance by the operation of jet tubes is a more effective means of reducing elevation errors than is provided by the fitting of internal temperature tubes. On the average these jet tubes reduce the residual elevation error to a value of about −1 second. (3) Thermograph records taken continuously during the trials indicate that for these instruments within the range of temperatures from 10 C to 15 C the variation of coincidence adjustment at zero angle of sight is not greater than 0.25 second per degree centigrade.

5.2 THERMAL EFFECTS IN STEREOSCOPIC RANGE FINDERS

5.2.1 Charging with Helium

It will be noted that these earlier experimental observations on elevation error and temperature effects were made on range finders of the coincidence type. The Princeton Laboratory at Fort Monroe first studied these thermal effects in the stereoscopic type instruments. (345) In theory, developed in the report and given at considerable length as an appendix, vertical temperature gradients along the optical paths of a height finder will produce refraction of the light rays in a vertical plane. If such stratification exists, when the instrument is elevated, this refraction will produce an effect on the plane of triangulation proportional to the sine of the angle of elevation. With a temperature gradient of 1 F per inch in the M1 13 1/2-foot Height Finder, this effect amounts to 40 seconds total angular refraction over a path length of 29 feet if the instrument is charged with dry air or nitrogen. Parts of this total refractive angle compensate each other leading to a smaller error which depends on the angle of elevation at which the internal adjuster readings and range readings are made. In this case, the range error in reading on an aerial target at 4,000 yards altitude and true slant range 8,000 yards is 23.3 UOE if the internal adjuster is read at the same angle. The magnitude of the stratification effect depends on the refractive index of the gas and is directly proportional to the excess of the refractive index over unity. For nitrogen or dry air this excess is 29×10^{-5}. For helium it is 3.6×10^{-5}. The stratification effect, assuming equal temperature gradients and equal gas pressures, would therefore be reduced to about 12 per cent of its previous value by the substitution of helium for nitrogen. The stratification effect with a gas mixture cannot be obtained with complete accuracy by linear interpolation based on percentage composition because of an additional effect due to thermal diffusion. But it is estimated that a mixture of 95 per cent helium and 5 per cent nitrogen would reduce the stratification effect to about 19 per cent of its value for an instrument charged with pure nitrogen.

The Princeton Laboratory then proceeded to test this theory experimentally, using the internal adjuster system of the M1 Height Finder. To accomplish this it is necessary only to produce a uniform vertical temperature gradient within the main tube and determine the difference between the internal adjuster settings taken, first, with the plane of triangulation vertical and, second, with the plane of triangulation horizontal. The size of this difference depends only on the magnitude of the temperature gradient and on the refractive index of the gas with which the instrument is charged. Inasmuch as facilities were not available for the creation of extreme or uniform temperature gradients, an alternative method was employed. This consisted of using a height finder soon after it was moved from the shade and exposed to the sun. Thermocouples were placed at various points within the instrument and it was found that differences in gas temperature between the top and bottom of the main tube as great as 1 F per inch are sometimes produced by this exposure to the sun. Thermocouple measurements have also shown that the temperature gradients resulting from this exposure are not constant along the axis of the main tube and that the temperature distribution within the instrument is otherwise not uniform. For example, gas temperature differences as great as 4 F have been observed between the two ends of the instrument, and smaller differences of metal temperatures have been found to exist between the ends of the optical bar.

It is also possible that differences in internal adjuster settings for the two positions of the plane of triangulation may be due, in part, to factors other than temperature stratification. From the data of this study there is strong evidence that not all instruments behave in the same way. This type of variation, which may be due to differences in construction,

makes difficult the isolation of that part of the observed differences in internal adjuster readings due only to temperature stratification. It is likewise possible the observers vary in their reading of the internal adjuster as the instrument is elevated or depressed, due perhaps to the change in head position. In spite of these difficulties, the present experiment established qualitatively that the theoretical stratification errors occur as predicted. Further work was needed for quantitative verification. As shown by the stratification theory, the magnitude of the effect of elevation on internal adjuster readings is determined, in part, by the refractive index of the gas with which the instrument is charged. This fact makes possible a further experimental verification which was accomplished in this study by the use of instruments charged with helium and, at different times, with nitrogen, the effect being almost entirely eliminated when helium was used. Finally, the experimental evidence that the use of helium reduces the refractive errors proves the practical advantages of using this gas for charging the instruments in the field. For example, for one instrument the elevation error was found to be -11 seconds when charged with nitrogen and this was reduced to -2 seconds or $+1$ second for two comparable days when charged with helium, or a reduction to about one-eighth of the error.

In this report a brief study was also reported of methods for charging the height finders. In changing from nitrogen to helium the two methods used successfully were flushing and evacuation. Evacuation is quite satisfactory, but under field conditions may be inconvenient. Experiments were, therefore, carried out on the time required for adequate flushing. In several cases, after flushing with 50 cubic feet of helium, the content of nitrogen remained well below 5 per cent. For economy of helium, flushing should be carried out at low rates of flow. The important quantity is the number of cubic feet passed through and 50 feet seems advisable for the M1 instrument. This is attainable, where tank pressure gauges are not accessible, by flushing for at least 45 minutes holding at least 5 pounds gauge pressure.

From these results the investigators conclude that both the theoretical and experimental evidence indicates the desirability of filling M1 height finders with helium since this will necessarily reduce all refractive errors and since there is no respect in which helium appears inferior to nitrogen as a charging gas. In order that the M1 height finder be charged satisfactorily with helium, it should be flushed for 45 minutes at 5 pounds pressure to ensure that the final charge is at least 95 per cent helium.

Prior to this Princeton Laboratory report, the same group published some preliminary results on this topic of temperature effects. (343) In this report are given the position of the thermocouples introduced into the M1 Height Finder and temperature trends measured by them in different parts of the instrument. Some preliminary results of elevation errors are given and helium is suggested as one means of reducing thermal gradients in the system.

Princeton Laboratory at Fort Monroe has also presented a large number of special studies dealing with stratification effects. These reports give in greater detail the experiments summarized in their larger final report. (345) One report outlines the experimental determinations of the extent to which internal adjuster readings are modified by elevation and is aimed to discover how much of this effect can be attributed to long exposure to the sun. (430) Another considers the best method of making the RCS setting for these experiments. (431) The next report outlines the temperature characteristics of different instruments; (432) and the differences found by testing two M2 and two M1 instruments are tentatively assigned to differences in effective insulation. Still another report describes the place and method of installation of thermocouples in two M1 Height Finders. (433) Another paper deals with the effect of temperature on the internal adjuster setting when ranging on fixed ground targets. (434) With no change in elevation, there is shown no significant relation between temperature and the RCS setting for the M1 Height Finder over a temperature range of 35 degrees F. Similar plots for the M2 instrument show a well defined relation; for each degree Fahrenheit increase in temperature, RCS readings decrease by about 0.6 units.

Another Princeton Laboratory report gives results indicating the reduction of the stratification error when the instruments are filled with helium as contrasted with nitrogen-filled instruments. (435) Another report gives thermocouple measurements of internal temperatures. (436) Air temperatures were measured at the top and bottom of the internal adjuster wedge cavity; and at the objective side of the left reticle frame. Temperatures of different parts of the instrument were measured at the top and bottom of the range prism cavity and the metal temper-

ature, outside of back wall of the optical bar. It was demonstrated by these readings that differences of considerable size exist between different parts of the instrument. For example, air temperature at the bottom of the internal adjuster wedge cavity might be considerably above the outside air temperatures after prolonged exposure to the sun. Also temperatures at the optical bar lagged behind the more exposed portions of the instrument. Another report gives additional information regarding thermocouple measurements taken on an exposed instrument throughout a day with temperatures varying from 8 to 100 F. (438) Another report describes the filling of two instruments with helium. (437)

These studies are summarized in the Princeton Laboratory report described above which is attached as supporting data to a Report to the Services issued by the Fire Control Section of NDRC. (1) In this report attention is called to the considerable body of evidence indicating that ranges obtained from optical range finders may be in error by appreciable amounts at times when the external temperature is changing or when the instruments are exposed to direct radiation from the sun. It was pointed out that temperature stratification of the gas within the instrument could cause such errors, and that they would be much reduced by filling the instrument with helium. The recommendation was made to the Services that all range and height finders intended for high elevation observing be charged with helium. This recommendation was adopted by both the Army and Navy for all high elevation range finders.

5.2.2 Causes of Temperature Changes

About a year later, in October 1942, the Fire Control Section of NDRC issued another Report to the Services on temperature effects in stereoscopic height finders. (16) Five studies are attached as supporting evidence which will be analyzed below.

Temperature changes may be induced in a range finder in a variety of ways. The temperature of its surroundings may change gradually, in which case the temperature of the instrument changes in such a way that at any one time all of its parts are at substantially the same temperature. The temperature of the surroundings may change rapidly, in which case different parts of the instrument will be at different temperatures. Or the instrument may be exposed to direct sunlight, so that certain portions of the instrument are raised to and maintained at temperatures materially above those of its surrounding air, and materially above other portions of the instrument. These causes may produce a wide variety of effects, either on the gas which the instrument contains, or upon the structure of the instrument itself.

If a gas is maintained under constant pressure and its temperature rises, its density, and therefore its refractive index, decreases. This change of refractive index, if uniform, may cause slight, though not entirely negligible changes in the focal lengths of the optical systems immersed in it. For example, in the stereoscopic height finder, the image of the target, which is ideally supposed to be formed in the reticle plane, will change position slightly. The direction of shift will be along the optical axis. Since shifts of this kind also occur as the distance of the target changes and since the importance of these perspective errors is discussed in another report which is described above (18) no further mention of them will be made here.

Stratification

If the temperature is not uniform throughout the gas, three types of phenomena may occur. The gas may form fairly stable layers hot at the top and cool at the bottom. In this case any beam of light passing lengthwise throughout the instrument will be deflected downward. This is the stratification effect discussed above. (18) The hotter parts of the gas may also form in stagnant pockets, the boundaries of which will in general be curved. Such pockets will act as rather weak and ill-defined lenses or wedges, thus both blurring the images and shifting them relative to the reticle. The shift in this case may be either along the axis or normal to it. Finally, convection currents may be set up, the curved boundaries of which may affect a beam of light in exactly the same way as would a stagnant pocket. In addition, these pockets transport heat from one part of the instrument to another and thereby cause inequalities in the temperature of its structural parts. For example, such a current might flow upward along one side of a plane mirror making that side warmer than the opposite face, and thereby causing curvature.

All of the effects so far mentioned are alleviated

by the use of helium as a charging gas, partly because its refractive index differs so little from unity at all temperatures, and partly because its thermal conductivity and viscosity aid in the rapid elimination of temperature differences within the gas itself, or between the mechanical parts immersed in it.

There is another and largely unrelated set of temperature effects in the gas due to its expansion and contraction with temperature. The instruments under discussion are in all cases initially sealed, but they are subject to large temperature fluctuations, and therefore to rather large extremes of internal vacuum or pressure. Since the seals are not perfect, gas is alternately expelled and inhaled; in other words the instrument breathes. This, in the case of helium-filled instruments, causes contamination of the helium. In all instruments it leads to the introduction of a certain amount of water vapor, which, particularly in the case of Naval instruments or in the tropics, may cause the optics to fog.

As soon as the use of helium had been standardized by the Services, steps were taken to determine how much the instruments would breathe. Results of this study were reported in a subsequent Report to the Services. (26) However, sufficient data was on hand to show that though instruments fresh from the factory frequently breathe very little, after they have been in service for a time many of them breathe a great deal, and occasional ones leak like sieves.

This result had been expected and consideration had been given to possible methods of correction. The obvious possibilities are control of temperature and control of pressure. Of the two, temperature control seems the least desirable because it would require a constant source of power during periods of storage or transportation and, unless very carefully worked out, might create more temperature problems than it eliminates. It was therefore decided to investigate methods of breathing by control of pressure. The American Gas Association Testing Laboratories developed such a device. Results of its use and the description of the apparatus are given below. In connection with these developments, it should be pointed out that if the pressure within the range finders can be successfully maintained within a very few ounces above atmospheric at all times, the seals of the instruments will in all probability last longer than at present, since it is probable that the initial breakdown of these seals is commonly caused by the extremes of pressure or vacuum due to temperature changes.

Structural Changes

This report then goes on to consider temperature effects on the structural parts of range finders. Mechanical effects have been observed principally at low temperatures where bearings sometimes freeze and lubricants congeal. In the case of Army height finders M1 and M2, these effects are known to be serious. It is probable that a satisfactory solution would require redesign, but this would obviously not correct existing instruments now in the field. To alleviate the situation with respect to existing instruments, therefore, an electrically heated jacket was designed by the General Electric Company which in severe cold will keep the working parts of the instrument warm enough to assure freedom of movement. This was developed under the auspices of the Fire Control Design Section of the Ordnance Department, Frankford Arsenal, and is believed to be the most practical method of alleviation.

Temperature effects in the structure of a height finder affect its optical performance in a number of ways. As the temperature of a lens rises, its radii of curvature increase, and its refractive index decreases. Both of these changes tend to increase focal length and lead to changes of adjustment of the perspective type. These will occur even if the temperature change is slow and uniform. When the temperature changes are nonuniform, more complicated distortions occur. These appear not to have been adequately studied and are not well understood. Nonuniform temperature in mirrors, such as those used in pentareflectors, causes their plane reflecting surfaces to become curved. This may either introduce lens action, thus leading to perspective errors, or may alter the angle of the beam relative to the axis. Nonuniform temperature in the supports of the pentareflectors may cause an alteration of the angle between the mirrors. This has been estimated and the magnitude has been found to be significant.

Uniform temperature changes in the optical bar cause it to expand, thereby lengthening the distance between the various optical parts. That is advantageous, in some cases at least, since it tends to compensate for the increasing focal length of the lenses. Nonuniform temperature changes in the optical bar, however, cause curvature which, if in the plane of

triangulation, may lead to range errors. Temperature differences of the order of a degree between opposite sides of a bar are reported experimentally and it is estimated that a temperature difference of this magnitude would produce a 40-second curvature in the standard optical tube.

The suggestion has frequently been made that the errors due to nonuniform expansion of these structural parts could be largely alleviated by substituting invar and quartz in place of steel and glass. Some years before, the Bausch and Lomb Optical Company constructed an invar optical bar. Keuffel and Esser had also experimented with bronze and with invar for the end-reflector supports, and with aluminum for the optical bar. Officials of both companies state that no improvement was observed, probably because the effects under investigation were masked by errors due to stratification and other causes. At the time of this report an M1 and an M2 Army Height Finder were being equipped with invar optical bars in order to permit an accurate comparative study to be made. An elaborate system of thermocouples was also introduced into these instruments to measure internal temperatures accurately and continuously. The M1 instrument will have, in addition, penta-reflectors consisting of quartz mirrors mounted in invar supports.

It should be noted that many of the effects of nonuniform temperature, particularly those resulting from direct radiation, could be mitigated by the use of some form of sunshade. The practicability of such devices under field conditions is believed doubtful. One further effect of temperature changes in structural parts is mentioned. If at any point the mechanical design of the instrument is such that expansion of a particular part can induce strains in sensitive optical supports such as the optical bar or the mounts for the penta-reflectors, errors may occur. Princeton Laboratory experiments revealed the largest temperature errors which have ever been observed. They were present in most but not all of the instruments tested, and their behavior was sufficiently erratic and mysterious that it was impossible to trace their origin under the conditions of the experiment. Enough was learned, however, to indicate quite clearly that they were of mechanical origin, and their further study was transferred to the Eastman Kodak Company, where instruments in various stages of assembly and subassembly were available for test. These tests have shown that the errors arose from pressure exerted on the optical bar by the change-of-magnification lever, and that they can be completely corrected by a very simple adjustment which can easily be made in the field.

The above discussion has called attention to a wide variety of temperature errors. Attention is also called to suggested methods of alleviating most of these, either in instruments in the field, or by new design or construction of structural parts, or the use of new materials in the manufacture of these structures. The process of correction so reported, however, has been that of piling one modification after another on existing instruments. Such a process must ultimately lead to a situation where complete redesign is indicated. It was believed (October 1942) that this time had come; for the present instrument, when all the recommended gadgets are attached, has no unity of design. Moreover, the experience and technical information which has been gained in the course of these experiments is considerable, and would be of great value as a guide to redesign in a more fundamental sense. Much of it resides in the minds of the men who have been associated with the research program, and is unreported and intangible. Hence it is believed that a basic redesign of the stereoscopic range finder should be undertaken at that time.

This last recommendation was put into effect and the results of this redesign program will be reported in a subsequent section of the present report. Later in this same section the results are summarized of experiments using new materials for some of the structural parts.

Effect of Accuracy

Attached to the Report to the Services just summarized above are five supporting documents giving in detail the theoretical and experimental basis for the statements made in that report. The first of these, on the effects of thermal instability on height finder accuracy is made by the Princeton Laboratory at Fort Monroe. (347) In this are given more complete experimental results and expanded theoretical discussion of the effect of temperature stratification in a vertical plane on height finder readings. These data supply the quantitative values for the qualitative findings of the earlier Princeton report, with instruments charged with both nitrogen and helium and with thermocouple readings indicating the magnitude of the temperature gradients. In some of these

experiments a circulating pump was installed for the purpose of eliminating temperature stratification. Two instruments were kept at 0 degree C overnight. Upon removal from the cold room, both instruments showed marked errors in range readings —the range sometimes short by 20 to 25 UOE. The maximum error was reached about an hour after removal from the lower temperature. It was 4 to 5 hours before the instruments again read true range. The substitution of helium for nitrogen reduced the error to less than 3 to 5 UOE. The error remaining was too small to evaluate with great accuracy. The two instruments behaved differently possibly because the aluminum temperature tubes and baffles were removed from one instrument and not from the other. The circulating pump was found unsatisfactory in its present design.

A second Princeton Laboratory report describes a method of charging Height Finders M1 and M2 with helium. (352) This is given in manual form and is to be used as a guide for methods of charging instruments in the field. A helium purity indicator is described and methods of determining the percentage helium in an instrument are given. Methods for charging and testing height finders with helium without the aid of a helium purity indicator are also described.

The third Princeton Laboratory report again deals with studies of range finder errors caused by temperature instability. (358) This report presents experimental evidence that serious errors exist in certain instruments when these instruments are subjected to too rapid changes of temperature or to nonuniform heating by the sun's rays. In the M1 instrument these erroneous readings result from refractive errors caused by bending of light rays, and also from structural errors from bending of mechanical and optical parts. It is shown that the refractive errors are nearly eliminated through the use of helium as a charging gas. In this report the geometry of the M1 Height Finder is briefly and clearly given as a basis for the discussion. Errors as great as 11 UOE are found for nitrogen-filled instruments under certain conditions. Experiments on mechanical effects were performed with an artificial sun consisting of a bank of 38 low-temperature 250-watt drying bulbs as energy sources so that nonuniform heating effects could be obtained. When applied to the top of the height finder near the ends of the tube all but one of the instruments exhibited decreases in internal adjuster readings of 100 UOE or more in a few minutes after the artificial sun was turned on. These effects essentially disappeared if the instrument was depressed below about 60 degrees angular height. The effects were of about the same magnitude independent of gas content. What range readings were available indicated that essentially all of the RCS change was caused by changes in the main optical path. Only very small effects were observed when the radiant heat was applied to the sides or above the central part of the instrument. Tests on two instruments showed that they, at least, had sensitive spots in the neighborhood of the internal adjuster lamp housings. For example, shielding these spots in one particular instrument reduced the observed RCS changes by a factor of 6.

An Eastman Kodak Company report repeated these experiments with the artificial sun and found that one particular instrument exhibited a reduction of 90 UOE in the internal adjuster reading with the finder set at 1,600 mils after the artificial sun had been on 30 minutes. (203) The second instrument showed only a small shift under the same conditions. It was found that when the clearance between the change-of-power lever and the change-of-power disk was made adequate, the first instrument no longer exhibited the large shift in the reading but was like the second range finder. Examination of 13 uninspected height finders revealed that the disturbing shift would take place in at least four. Of six instruments tested by the Princeton Laboratory, five showed the large effect. Hence it was recommended that in new range finders, the design of the change-of-power lever be altered to provide increased clearance between it and the change-of-power disk. Furthermore, for all M1 Height Finders in the field, it was recommended that, as specified above, 1/16 inch washers be inserted between the bearing plate for the change-of-power lever and the boss on the outer tube.

5.3 ELIMINATION OF THERMAL ERRORS

A report from the National Bureau of Standards comments broadly on temperature errors and suggests a radical redesign to eliminate them. (320) It is pointed out that the chief causes for the inconsistent performance of range finders are: (1) temperature gradients in the air within the body of the instrument; (2) binding of the optical tube or bar, produced either by mechanical strain or by temperature

gradients; and (3) variation in the deviations produced by the two penta-reflectors due to nonuniform expansion resulting from temperature gradients. In eliminating the errors due to bending of the optical bar a design is suggested for an optical tube with the two systems placed side by side instead of end to end. Fused silica end plates are also suggested.

The Princeton Laboratory at Fort Monroe prepared a number of individual and more detailed studies which are summarized in the reports attached as confirming evidence to the Report to the Services discussed above. The first of these is concerned with RCS determinations on helium-filled and nitrogen-filled instruments. (439) It was found the RCS at zero elevation on the M1 instrument does not depend on the temperature level. Under conditions of temperature instability, RCS at zero elevation undergoes changes, probably connected with temperature differences within the instrument. These zero elevation changes are not primarily effects of refraction of the gas within the instrument, since they are unaffected by the substitution of helium for nitrogen. However, RCS at 1,600 mils elevation may differ from that at 0 mils. This difference is affected by the gas within the instrument and may, therefore, be in part a refractive effect.

The next report is a preliminary study of the effects of circulating gas within the height finder on internal temperatures. (440) Another report, a theoretical study, concerns the effects of temperature stratification on height finder accuracy. (441) The technique of testing and flushing helium-charged height finders is the subject of the next report. (442) This gives detailed procedures already referred to above.

A report by the Princeton Laboratory deals with experiments to determine quantitative relations between thermal and optical conditions in an M2 Height Finder. (443) It describes in some detail the experiments carried on by cooling the instrument overnight in the cold chamber. The experimental results obtained are given in a following report. (444) From this work it is concluded that at 1,600 mils elevation the averaging thermocouples were highly successful in predicting the refractive effects in the main optical path. Also, the use of helium as a charging gas reduced the temperature gradients developed under these conditions by a factor of 5.

Another report from the Princeton Laboratory is concerned with the kinetics of the warming process in a modified M2 Height Finder. (445) This consists of a further analysis of results obtained from keeping the instrument in a cold room overnight. It was found that the relaxation time with no helium is 1.5 to 1.7 times as large as that with pure helium. Thus, in the helium-filled instrument much of the heat flow (30 to 35 per cent) is carried off by the helium. It is believed that the warming of the optical bar is the controlling factor in this warming process. It was found that a purity of 54 per cent helium was little better than no helium in cutting down the relaxation time. Another report describes in detail the theory and apparatus for the experiments with the artificial sun.

It was pointed out above that range finders breathe and that, unless precautions are taken, replenishment would have to be of fairly frequent occurrence in order to maintain adequate helium purity. It was also suggested above (16) that one way of dealing with this problem would be to maintain a gas pressure within the range finder slightly above the pressure of the outside air. The Fire Control Division of NDRC has prepared a Report to the Services on this problem of the retention of helium in range and height finders (26). All range finders breathe more or less. That is, as the temperature rises, the internal pressure increases and gas escapes through imperfections in the seals. As the temperature falls, the internal pressure also falls, and when it becomes lower than the atmospheric pressure, air is sucked in. This breathing is undesirable under any circumstances, since it introduces moisture into the instrument. It is particularly undesirable in the case of helium-charged instruments because the purity, and therefore the effectiveness, of the helium charge is reduced. As soon as it became evident that stratification errors could not be effectively reduced in American range finders by pump agitation, and that the use of helium was necessary, a study was undertaken to determine how rapidly the helium became contaminated. This study was begun at Fort Monroe on several instruments that were being used in the Height Finder School, and was extended to include the performance of Army height finders and Navy range finders under Service conditions as soon as the adoption of helium by the Services made this possible.

The detailed report from the Princeton Laboratory is attached to this report to the Services. (369) Stated briefly, the study showed that the majority of

instruments were tight enough to hold helium for periods ranging from 1 to 6 months. It was believed that most of the remainder could be made reasonably tight by repairing the gland packing and other seals. Helium purity indicators were used and internal adjuster readings were taken on at least one helium charge of 445 Army and Navy instruments. The helium purity indicator proved a satisfactory testing instrument. To insure that the range finders be kept at an average helium percentage of 90 per cent, with sufficiently small variation to give satisfactory service, recommendations were made that all range finders which are not excessively leaky be charged, and when necessary recharged, to 95 per cent helium, and that any range finder which tests below 88 per cent be regarded as requiring recharging. In an appendix to this Princeton Laboratory report the Oliver Helium Charging Method is given in detail. Detailed data regarding leakage is given in another appendix.

5.3.1 Prevention of Helium Contamination

While these studies (26) of helium retention were under way, the American Gas Association Testing Laboratory was asked to develop means for controlling the breathing process, thereby preventing helium contamination. They developed an attachment for this purpose which is described in four reports appended to the Report to the Services. (62, 63, 64, 65) Briefly, it consists of a bellows directly connected to the interior of the height finder permitting the gas to expand and contract freely at a pressure only about 1 ounce above atmospheric; a relief valve which allows gas to escape when the bellows is fully expanded, thereby preventing high internal pressures from developing; and a small high pressure helium supply from which helium is introduced into the range finder through a sensitive reducing valve when necessary to prevent the internal pressure from falling below atmospheric. The apparatus has been so engineered that it can be attached to existing range and height finders by merely replacing the desiccating plug by a suitable adapter. In the case of the M1 Army height finder, it has been designed within the space limits of the present carrying case, so that the breathing apparatus will continue to function, and contamination of helium will continue to be prevented even during the periods of storage or transportation. The apparatus was tested under a variety of conditions.

Strictly speaking, the only portions of this apparatus which are necessary to prevent helium contamination are the supply tank and sensitive reducing valve. It is therefore desirable to explain why the bellows and relief valve were added. This can best be done by assuming that we had, initially, a very tight instrument to which were attached only the supply tank and reduction valve. In such an instrument the pressure could never go below atmospheric. However, as the temperature rose, a very considerable internal pressure would develop. At the same time, the seals would be softened by heat and under extreme conditions would break down and allow gas to escape. Once being weakened by such a breakdown, they would fail easily on subsequent occasions. Therefore a situation might be expected to develop in which substantially all of the gas introduced through a period of falling temperature would leak out during the subsequent rising part of the cycle, thus leading to an excessive consumption of helium.

That this process actually does take place is confirmed by a test reported by the American Gas Association Testing Laboratories. (64) In this test, an Army height finder, originally in better than average condition, was subjected to successive cycles of rising and falling temperature under carefully controlled laboratory conditions. During the first cycle of rising temperature, the internal pressure rose in normal fashion to a maximum value of 26 inches of water, at which point it abruptly fell to about 4 inches, though the internal temperature at the time was still rising. The damage to the seals in this cycle was sufficiently great that the internal pressure thereafter never rose above 6 inches of water. The bellows and relief valve have been included in the A.G.A. equipment to prevent such occurrences. They reduce the consumption of helium both by keeping the instrument tight and by keeping the pressure differential so low that only a small amount of gas escapes even from a moderately leaky instrument.

Another possible method of discouraging breathing is by maintaining the entire instrument constantly at a temperature above the maximum to be expected from diurnal variations. This could be done, for example, by means of an electrically heated jacket. There was no background of experience upon which to base an appraisal of its merits, but three disadvantages may be suspected on theoretical

grounds: (1) the difficulty of maintaining the system in operation during periods of transportation or storage; (2) contamination due to breathing induced by changes in barometric pressure (the range of which is about 10 per cent of mean atmospheric pressure and therefore equivalent to a temperature range of about 40 F); and (3) optical disturbances induced by inequality of heat transfer. The method was therefore not regarded as desirable.

The Fire Control Division of NDRC recommended that the A.G.A. pressure control attachment be adopted for all helium-filled range and height finders. The recommendation by the Princeton Laboratory in regard to the Oliver helium charging method is not endorsed. It is pointed out that the Oliver method will guarantee adequate helium purity under only one specific set of circumstances, namely, when an instrument is being recharged. It is therefore a valuable method for use when a helium purity indicator is not available. It does not, however, give an indication of the percentage contamination of the helium. Such an indication is desirable, both in order to know when recharging is necessary, and in order to detect and correct promptly any unusual causes of contamination. Hence, a satisfactory helium purity indicator is believed preferable to reliance on the Oliver method. Such a purity indicator was subsequently developed by the American Gas Association Testing Laboratories under the auspices of the Navy Bureau of Ordnance.

There are several more detailed studies by the Princeton Laboratory at Fort Monroe on matters of temperature control in range finders. One deals with the retentivity of range finders and height finders in the field. (448) A second study describes the Oliver helium charging method. (450) A third outlines certain tests made at the Eastman Kodak Company using the artificial sun and reports, for one instrument, range errors as great as 30 UOE when the instrument was so heated. (451) These errors were reduced after the instrument was flushed with helium or was partially evacuated.

A Princeton Branch Frankford Arsenal report deals with oil contamination from ordinary helium. (236) It discusses the question of whether the use of ordinary helium as a charge for height finders would result in serious contamination of the optical surfaces by oil. After outlining such matters as the amount of oil required for serious contamination, the expected amount of oil in ordinary helium and the like, the conclusion is reached that serious contamination is not to be expected.

Certain comments and experiments on temperature control have been reported by the British. ARL reports an investigation of the extent to which an excess internal pressure can be retained in a modified American M1 instrument. (102) At the commencement of this test, the range finder was charged with air at a pressure of 4.5 psi and the subsequent decrease in pressure, observed over a period of 30 days, was noted. The instrument was used on the average of 2 to 3 hours per day. It was found that the pressure decreased to about 1 psi in the course of the first week. Subsequently the decrease was slower and even after 30 days there still remained an excess pressure of 0.25 psi. The degree of sealing efficiency revealed by this test is unapproachable by that of any British instrument examined up to that time by ARL. With British instruments, excess of internal pressures are held for a matter only of seconds or minutes. The report indicates reduction of elevation errors by air stirring under Service conditions. It is perhaps because of this inadequate sealing of the British instruments, that the British resorted to air stirring rather than the use of helium to reduce elevation errors. Indeed, in another British report, this is rather explicitly stated. (105)

Another British report describes experiments dealing with elevation errors in a U. S. M1 Height Finder at ARL. (103) With air filling, the elevation errors were found to be rather less than with an 18-foot British instrument, Type FQ 25, fitted with internal temperature tubes. Filling the range finder with hydrogen in place of air has been found to reduce elevation errors to approximately half the values obtained with the air filling, while, with helium filling, elevation errors were reduced to about one-third or one-quarter. The reduction of elevation error effected by charging the instrument with helium is substantial but, on occasion, errors of —2 to —3 seconds in the object space were detected. The zero elevation temperature coefficient was found to be approximately 0.14 seconds per degree centigrade and therefore similar in magnitude to those present in the average British range finder.

5.3.2 Air Stirring

Still another British report by ARL deals with a study of the removal of elevation errors by circumferential air stirring in the U. S. M1 Height Finder. (50) In this instrument, the internal beam shrouding

tubes were removed and air jet tubes were filled to permit the application of circumferential air stirring. Tests were then carried out to determine the efficiency of air stirring as a means of removing elevation errors in the instruments. The results show that air stirring, either by means of a hand pump or by means of a motor-driven pump (the Naval pattern Q.G.2) reduced elevation errors of all magnitudes to residual errors of the order of 1 second. A comparison of the results obtained with air stirring with those obtained with helium filling, in the British study reported above, shows that air stirring appears to be slightly more efficient than helium filling in reducing elevation errors. With the internal beam shrouding tubes removed, it was found that, as expected, the internal adjuster did not give an accurate means of checking the errors of the Height Finder unless air stirring was in operation. Comment may be made regarding the final conclusion reached by this report that air stirring is slightly more efficient than helium charging. The air stirring of this report is compared with results of the previous ARL report on helium charging. (103) In regard to the helium study, for some reason the introduction of helium failed to produce as great a reduction in elevation error as should theoretically occur. The causes of this failure were not discovered. In view of the fact that the American experiments have repeatedly secured the theoretical measure of improvement, it is natural to suspect that a part, at least, of the elevation error observed in the British experiments was due to causes other than stratification, perhaps to some form of mechanical strain causing flexure in the optical bar. It is these data, which are not as favorable as would be expected, which are used as the basis of comparison with air stirring.

In an effort to reduce stratification due to temperature changes by partially shielding the range finder from the radiant heat of the sun, and hence supplement the helium charging of the instrument, Brown University reports the development of a height finder sunshade. (152) This can be readily assembled in the field from wood and canvas and is easy to install or remove. It covers the two ends of the instrument beyond the tracking telescopes. Detailed description and procedure for assembly are given.

5.3.3 Cold Weather Tests

A series of cold weather tests of height finder performance is reported by the Frankford Arsenal. (251) The tests were designed to determine the effects of M404 and M405 electrically heated covers on the mechanical and optical performance of the height finders under actual Arctic field conditions. The tests were carried on under conditions of extreme cold in north-central Canada during 10 weeks from January to March. Two M1 and two M2 instruments were tested continually throughout this period, both with and without the use of the two electrically heated covers. During this period, the temperature varied from −34 to +16 F, with a mean temperature of −10 F. Thermal stratification, as determined by both thermocouple measurements and internal adjuster readings at various elevations, was found to be negligible without cover heat and considerable when heat was applied. In most cases, the temperature gradient pattern reached stability quickly, about 2 hours after the application of heat, and appeared to be independent of the internal temperature which reaches stability relatively slowly after about 20 hours. The internal temperature gradients may be explained by appreciable external gradients produced by the heated covers and are progressively reduced at ambient temperatures of −5 F and higher.

Aerial targets of known position were not available for testing purposes. The M1 Height Finders functioned satisfactorily in ranging to ground targets under all operating conditions, but the M2 instruments functioned satisfactorily only when cover heat was applied. The M1 Height Finders tested were, with few exceptions, superior in mechanical operation to the M2 Height Finders at all temperatures. In fact, without the installation of the covers the M1 instruments operated satisfactorily at temperatures as low as −30 F and functioned in a normal manner at +16 F. The installation of the cover and the application of heat improved the mechanical operation in general. With heat, the M1 instrument operated in a normal manner at −20 F. However, some of the M2 mechanisms operated unsatisfactorily at −13 F, even with the heat.

It was observed that ocular fogging is probably the most serious difficulty encountered in the use of the height finder at sub-zero temperatures. This difficulty may be offset by the use of facial masks, of blankets placed over the observer's head and the instrument, or of heating coils to raise the temperature of the eye lens of the ocular. Helium charging, using either the helium purity indicator or the Oliver technique, presented no major difficulties at sub-zero temperatures. It was found that rapid temperature drops

increase the rate of helium leakage in the height finders, whether heated covers were used or not. Examination of the optical elements and various standard optical checks indicated that sub-zero temperatures (down to –34F) did not produce any serious optical difficulties nor were electrical defects of importance encountered in either type of instrument.

On the basis of these results it was recommended that M1 Height Finders be used without the electrically heated covers whenever their mechanisms will function properly in this condition and that M2 Height Finders should not be used for Arctic operations. If the cover becomes necessary for the M1, heat should be applied at least 10 hours prior to use.

A Fort Monroe Princeton Laboratory report outlines experiments which show that the calibration of the height finder is materially altered when helium is used as the charging gas. (449) In six different experiments, an instrument was set up and left mechanically undisturbed throughout the sequence of observations. Two or more observers read ranges on a fixed target and after several such readings, the gas content of the instrument was changed. The readings were then repeated with the new gas content. In one experiment the mean change from helium to nitrogen filling was –65 yards or about –4 UOE. In the final experiments in spite of observer differences the change from helium to nitrogen resulted in differences in range readings from 13.0 to 2.5 UOE and in the RCS setting from +4.9 to –2.7 UOE.

A report from the Naval Inspector of Ordnance at the Bausch and Lomb Optical Company reports experiments on the determination of parallax resulting from the charging with helium. (318) It was found that range accuracy is affected by the introduction of helium into the range finder, the magnitude of the errors depending upon the original adjustment of the instrument in air. With proper interpupillary setting, the average range error when the instrument is filled with helium is less than 1 UOE. The range errors with improper interpupillary settings in air and in helium are of such magnitude as to obscure the actual effects of helium. The average range errors due to the introduction of helium are not greater than errors existing between various range finders due to inherent optical or mechanical adjustments. However, it was found that a change of focus due to the introduction of helium was about 0.2 diopters, which closely approximates the calculated distance.

This distance was calculated by the Princeton Laboratory at Fort Monroe for the M1 Height Finder and was found to be very small. (517) Another Fort Monroe report details another calculation of the change of focus in the M1 Height Finder which may be expected when changing from nitrogen to helium. (516) The change in focus of the objectives is calculated as 0.411 mm corresponding to a shift of image from infinity to 568 yards. The internal adjuster objectives shift 0.93 mm corresponding to a shift from infinity to 1,340 yards. The image of the internal adjuster thus shifts relative to the reticle an amount corresponding to a shift from infinity to 400 yards.

A Frankford Arsenal Princeton Branch memorandum describes an instrument, called the *monofocle,* which is designed for use with the M1 Height Finder to measure the parallax between target and reticle. (232) This instrument indicates when the reciprocal range of an observed image differs from zero by more than a certain amount, expected to be approximately 0.1 diopter, or when the range to the image is less than a certain amount, expected to be about 10 meters. The theory and preliminary design of the instrument are given in the report.

5.3.4 Measurement of Focal Differences

A Frankford Arsenal Princeton Branch report studies the measurement of focus difference in the M1 Height Finder. (263) Irregular aberrations of substantial size have been observed in the target images formed by an M1 Height Finder. Mathematical study shows that, in the presence of such aberrations, the focus determined by a dioptometer will not give accurate indication of the focus difference between target and reticle effective in creating perspective error. The study describes an experimental model of a simple device, the aperture oscillator, which was designed and built. This instrument measures the focus differences effective in causing perspective error. It is as precise, under the conditions tested, as a dioptometer. The recommendation is made that aperture oscillators be used for checking height finder focus in the field and in inspection of new instruments and that consideration be given to the use of a similar instrument whenever lateral parallax must be avoided.

5.4 THERMAL EFFECTS ON OPTICAL BARS AND PENTA-REFLECTORS

In a Report to the Services summarized above, (16) it was pointed out that some of the thermal effects in range finders might be alleviated by the introduction of certain primary structures which would be less affected by temperature changes and thermal gradients. The results of several attacks on these problems will be described below.

5.4.1 Comparison of Invar and Steel Optical Bars

The Bausch and Lomb Optical Company reported laboratory tests on the comparative performance of invar and steel height finder optical bars. (114) Because field experience showed a strong probability that temperature effects on height finder optical bars introduced important ranging errors, a sample M2 bar was made of invar steel. Laboratory tests were made on this bar, on a standard steel bar, and on a standard steel bar with a polished nickel plate applied to the outside surface. These tests included: (1) the determination of the coefficient of linear expansion of the metals, using a one metal gauge length of the optical bars; (2) a determination of bending curves under induced transverse temperature gradients; (3) a search for parallax and other optical effects resulting from uniform temperature changes in the assembled optical bar; and (4) observations of range errors induced by transverse temperature gradients in the plane of triangulation. The experimental arrangements are described in the text. It was found that the coefficient of linear expansion, per degree C, within temperature ranges of 0 to 100 C averaged 1.8 for invar as against 11.55 for steel. The average radii of curvature under transverse temperature difference of 1 C were 0.99 for invar, 1.80 for standard steel, and 1.62 for bright nickel-plated steel. In the uniform temperature tests, over a range from 8 to 39 C with normal interocular separation, the range readings were erratic. Precision of an individual set of readings was less than 1 UOE. Consistency between sets was about 5 UOE. Changes in median of sets from one temperature to another were not over 5 UOE. No definite conclusions for this variability are drawn, but support friction may explain the fluctuations. Changing the interocular distance by ± 2 mm from the observer's interpupillary distance indicated parallax errors of about 3.5 UOE for the steel bars, and none for the invar bar. In regard to the range errors introduced by transverse temperature gradients, measured in UOE per degree C, the experimental results were very close to the theoretical calculated values of 2.3 for invar, 12.4 for standard steel, and 13.8 for nickel-plated steel. Hence it was determined that the materials have approximately their expected characteristics when fabricated as optical bars, and that the mechanical effects of transverse temperature gradients are proportional to the coefficients of linear expansion. As noted above there is indication of an uncontrolled factor in these experiments whose effect is not negligible. There appeared to be an erratic thermal lag, which may have been due to a combination of differential expansion between the bar and the temperature control jacket with friction in the supports. A reasonable stick-slip friction force may readily have introduced erratic errors of the kind found. Because of the nature of the experimental heating and cooling processes, differential expansion of the same order of magnitude was to be expected with the steel bar as with the invar bar. However, the results indicate that, in spite of these erratic fluctuations, the use of invar is capable of reducing range errors due to transverse temperature differences in the plane of triangulation by a factor of at least 5 to 1. Since field experience has indicated temperature differences across the bar sufficient to introduce ranging errors of approximately 20 UOE, it is obvious that a change to invar would be well worth while in height finder applications.

The investigators conclude from these data, for applications similar to height finder service where relatively large temperature gradients in the plane of triangulation may be expected, a design with an invar optical bar is to be recommended. For applications in which the instrument will be so shielded from solar radiation and the like as to minimize the danger of setting up large temperature gradients, invar cannot be unequivocally recommended. Means must first be found to reduce erratic errors arising from uniform temperature changes. If further experiments indicate that support friction is the chief cause of erratic behavior, invar optical bars may be recommended subject to improvement of the support mechanism.

A second report from Bausch & Lomb gives results

of additional laboratory tests of comparative performance of invar and steel optical bars. (116) These experiments indicate that the erratic errors arising from uniform temperature changes in the optical bar, found in the previous experiment, have support friction as a primary cause. This source of error was eliminated either by: (1) applying mechanical shock to the jacket enclosing the optical bar, when using the regular support, before recording range observations; or (2) supporting one end of the optical bar with a bifilar piano wire suspension. From these studies the investigators conclude:

1. For applications similar to height finder service, where relatively large temperature gradients in the plane of triangulation may be expected, a design with an invar optical bar is to be recommended. It must be recognized, however, that such a change does not account for other factors in range finder construction which have been eliminated from these experiments and which may tend to produce large errors under the above conditions.

2. For applications in which the instrument will be so shielded from solar radiation as to minimize the setting up of large temperature gradients in the optical bar, there is no appreciable difference in performance between invar and steel. The choice of the material may be safely dictated by other considerations.

5.4.2 Penta-Reflector Errors

A report from the Eastman Kodak Company deals with the effect of temperature gradient on mirror flatness. (202) There is first a theoretical discussion of the effects of different temperatures in the front and back surfaces of a plane mirror. The reflecting surface would then assume a spherical shape, concave if the temperature of the rear surface was greater than the front and convex if the temperature differences were in the other direction. With the present glass mirrors, using a height finder at 24 power, a focus shift of 0.007 seconds at the main reticle represents a 0.014-second shift at the eyepiece. The eyepiece focal length is about 28 mm so that a focus shift of 0.032 at the eyepiece represents 1 diopter. Hence a temperature difference of 1 F between the front and rear surfaces of one end mirror will cause parallax equivalent to 0.5 diopter measured at the eyepiece at 24x magnification. The effect varies directly with the temperature difference. If both end mirrors at one end of the height finder have equal temperature difference between their front and rear surfaces, the resulting focus shift is, of course, twice that which would result from the same temperature difference between the surfaces of just one mirror. When the mirror is made of quartz, which has a coefficient of linear expansion smaller than that of glass, the deformation is about one-twentieth as great, and the focus shift would be only one-fortieth diopter per degree Fahrenheit. To test these calculations, an experiment was performed using height finder mirrors of crown glass and of quartz. The curvature of the mirror was measured in terms of interference rings on a Twyman-Green interferometer. With both crown glass and quartz the experimental results closely approximated the calculated values. For the mirror of quartz, the path difference is only 10^{-5} mm per degree F, or in rings, one ring of interference for every 40 F temperature difference, while for crown glass it was approximately one ring for every 2 F temperature difference.

A further experiment was carried on by the Eastman Kodak Company in regard to the effect of temperature gradient on distortions of thin slabs. (207) Temperature gradients can be set up in penta-reflectors in any one of four ways: (1) radiation from nearby structures; (2) convection currents within the tube; (3) conduction by way of the supporting casting; and (4) temperature changes due to temperature gradients in all parts of the instrument. Each of these possible factors is considered theoretically in the present study. The conclusion is that distortion of the penta-reflectors does not depend on the thermal expansion coefficient of the material but also on the heat conductivity of the material. Curves of the curvature of slabs of different thickness made of various materials (glass, steel, quartz, invar, aluminum, copper, invar and aluminum, and quartz and copper) are given and the last named combination gives the best results. As a result of these findings, a composite block of quartz and copper was constructed and subjected to preliminary tests. These tests indicated that such composite blocks are more than sufficient to eliminate deviation errors in penta-reflectors.

Another Eastman Kodak Company report deals with the effect of temperature gradients in range finder penta-reflectors and carries still further the preliminary experiments noted just above. (205) It

is pointed out that the conventional types of range finder penta-reflectors consist of two plane mirrors securely mounted to a common support which maintains a fixed angular relation between them. From a functional standpoint it is important that there be no significant change in this angular relation, particularly in the plane of triangulation, over periods of time during which it is not feasible to make some compensation for the error. Previous investigations supported by data gathered in conjunction with this study have shown the existence of rather large temperature gradients in range finders subjected to conditions of varying ambient temperature. It was the purpose of the present experiment to study the effect of these temperature gradients on the light deviations of six types of penta-reflectors. The experiment was deliberately controlled to preclude the presence of significant gradients across the mirrors themselves. Hence these investigations are concerned solely with errors resulting from deformation of the mirror support due to the presence of temperature gradients. Measurements were made with an interferometer. Temperature gradients were measured by thermocouples. Standard penta-reflectors from the M1 and M2 Height Finders, the Mark 58 Range Finder, a quartz assembly obtained from the French battleship Richelieu, and a quartz assembly furnished by the National Bureau of Standards were tested and, in one experiment, also a Zeiss all-quartz block.

A first experiment to produce a maximum effect in the triangulation plane and for this purpose the heat source was placed directly behind the block. A suitable mask prevented radiation from falling on any but the rear surface area of the block. As the block was heated, simultaneous readings of the temperature gradient between front and rear surfaces and the orientation and number of interference fringes in the interferometer field were made at fixed intervals of time until the block reached a steady state of temperature gradient. At this point the heat was turned off and readings recorded until the block was once again in a stable condition. In a second experiment, to produce a maximum effect at right angles to the triangulation plane, the heat source was placed directly above the block.

The investigators conclude from these findings that the M1 block is obviously the poorest type, showing very significant deviation changes in both experiments. When allowance is made for the convection losses in the quartz blocks, the Richelieu assembly in particular is seen to behave quite poorly under the conditions of the first experiment. The M2 block seems very good, certainly the best in the first experiment and comparing favorably with the best in the second experiment. The Mark 58 shows up about average. All the blocks tested showed significant changes, i.e., changes which might well affect the accuracy of a range finder were they not compensated for in some manner.

From these observations it appears that the temperature effects in these blocks are not alone dependent on the coefficient of linear expansion of the material of which it is made, but also on the heat conductivity and the geometry of the block. For example, in the M1 the top and bottom portions are very thin and connected by members of a very small cross section, while the Mark 58 has relatively thick top and bottom portions and large connecting members. This fact, coupled with its smaller over-all size undoubtedly explains the better behavior of the Mark 58 block in both experiments. Simularly, the apparent superiority of the M2 block over the Richelieu seems to arise from the relatively large conductivity of the steel over the quartz, coupled with its smaller thickness. These two factors seem to more than cancel the effect of the very low coefficient of expansion of quartz. Hence, apart from the very necessary consideration of geometry, it appears that the best block is one with the highest ratio between its heat conductivity and its coefficient of linear expansion. On the basis of this criterion the present types of penta-reflector blocks are not satisfactory.

The Eastman Kodak Company designed several penta-reflectors in accordance with these principles and reports of their testing are contained in another report. (209) They are of composite construction and were found to be many times better than necessary for adequate range finder performance. The results of previous experiments indicate that quartz mirrors are probably preferable to glass for most installations, and that a quartz-copper or quartz-aluminum composite block approaches the ideal type of penta-reflector system more closely than the other designs which were tested. The results of these experiments seem to support the theoretical arguments pertaining to proper penta-reflector design: (1) that the angle determining member should be of some material with a very low linear coefficient of expansion, in which the presence of small temperature gradients will be insignificant; (2) that this member

be completely surrounded by a material of very high heat conductivity so as to prevent the formation of temperature gradients; and (3) that the outer shield be so mounted that it cannot transmit mechanical stresses to the inner member.

The copper-quartz composite block was designed primarily to fulfill these conditions. In its construction, two quartz mirrors are cemented to a quartz spacer. The spacer of this unit is then completely surrounded by a thick copper shield—the mirrors protruding up through this shield, which is separated from the mirrors and spacer at all points by an air gap of approximately 1 mm. Both the spacer and the inside of the copper shield were painted dull black. In the experimental design, the quartz was supported inside the copper shield between two small metal spring rings, although it is recognized that this is not a practical production design.

This composite copper-quartz assembly was tested comparatively against the standard M1 and M2 steel-mounted assemblies, an M1 and M2 block mounted on invar steel and a composite aluminum-steel assembly. It proved that the copper-quartz assembly was better than the standard M1, for top heating by a ratio of 45 to 1, and for back heating by a ratio of 24 to 1, combining the results both for heating and relaxation. The maximum deflection for the M1 is almost 23 seconds as against a maximum deflection for the copper-quartz block of 0.5 second for back heating. For top heating these values are, for M1, 28.6 seconds, and for the copper-quartz, less than 1.5 seconds of deflection.

The Eastman Kodak Company have reported further work on the reduction of range finder errors by modification of the penta-reflectors and the mounting of the optical bar. (210) This was a highly practical study to determine what modifications could be incorporated into the present M1 Height Finders to minimize these two sources of error and to determine methods by which these errors can be eliminated in an instrument of new design. To this end the characteristics of the range errors in the M1 Height Finder were investigated. One error reaching a maximum of 8 to 10 UOE between 1 and 2 hours after subjecting the instrument to a temperature change is caused by thermal gradients in the penta-reflectors. A second error often reaching a maximum of 30 to 40 UOE 8 to 10 hours after the temperature change results from mechanical stresses in the optical bar.

The present investigation has shown that heat is carried to and from the penta-reflector block predominantly by conduction through the supporting casting. Large temperature gradients are set up in the penta-reflector block as the heat is conducted to one side of the block which, in turn, is so constructed that the heat conduction across it is very small. These temperature gradients produce distortions in the penta-reflector block which change its reflecting angle.

Three possible methods of reducing the temperature gradients in the penta-reflector were investigated: (1) supporting the block on thermal insulators; (2) supporting the block from both top and bottom by steel diaphragms; and (3) covering the block with flexible copper braid. It was found that mounting the penta-reflector block on thermal insulators was undesirable because of temperature gradients resulting from convection currents. These gradients were about one-third as large as those set up by conduction. Supporting the block both top and bottom proved not to be feasible. The gradients between the top and the bottom of the block were greatly reduced in this case, but there was a large temperature difference between the front and the back of the block where the effect on the reflecting angle is a maximum. It was found that covering the penta-reflector block with flexible copper braid fastened to the top, bottom, and back of the block provided the most satisfactory solution. When enough copper braid was added to fill the available space surrounding the penta-reflector block, the temperature gradients were reduced to about one-third those in the unshielded block. The advantages of using the present supporting casting and mount offset any benefits to be derived from reducing the gradients further by the use of more shielding. This leads the investigators to outline the design of an ideal penta-reflector. It is obtained by designing to provide good heat conduction between all the parts so that temperature gradients will be impossible. This can be accomplished in two ways: (1) by making the separator out of a good conductor, such as copper, or (2) by making it of a material with low thermal expansion, as quartz or invar, which in turn is surrounded by a good conductor such as copper or aluminum. Some provision must be made for conducting the heat over the entire surface between the separator and the shield.

In regard to the optical bar mount, the present bar is supported at two places by three radial members, in the M1 Height Finder. A taper pin through one member prevents rotation and slipping of the bar.

This type of mount is supposed to support the optical bar free from all restraints, but the present tests showed that this was not the case. Mechanical stresses were transmitted to the bar by friction between it and the supports, and through the taper pin. The use of a kinematic mount, described in the text, was investigated, but it was not practical because of the flexibility of the optical bar. A mount giving the bar freedom of motion relative to its supports was developed in which the bar was supported by cast-iron rings, with a minute clearance between the rings and the support. The bar was kept in position by a pin, the end of which was turned to a sphere. This mount is very similar to the original Keuffel and Esser design. An M1 Height Finder was fitted with this type of mount and subjected to an ambient temperature change of 70 F. Range errors produced by the optical bar mount under these conditions could not be detected.

An M1 Height Finder was equipped with these modifications, consisting of the penta-reflector blocks covered with flexible copper braid and the optical bar mounted in the cast-iron rings described above. The modified height finder was subjected to an ambient temperature change of 70 F and the range errors determined by the internal adjuster. It was found that range errors resulting from the penta-reflectors were reduced from about 10 to 4 UOE by the copper shielding. Those originating in the optical bar mount were eliminated by the change in mount. A slow drift of about 10 UOE over a period of about 12 hours remains. This was originally attributed to the optical bar mount, but depends rather on the temperature of the height finder in a manner not yet determined. Thus, the range errors in the present M1 Height Finder can be materially reduced with rather simple modifications.

The report also indicates the nature and magnitude of these errors. When M1 Height Finders are subjected to ambient temperature changes of 60 to 70 F, the RCS values, as determined by the internal adjuster, follow a fairly definite pattern. The RCS starts to drift about 15 minutes after the temperature change, reaches a maximum shift of about 10 UOE in 1 to 2 hours, and then returns to approximately its original value after 4 to 5 hours. This short-time RCS shift is found in about the same amount in all height finders. Superimposed on this shift is a second long-time drift which starts about two hours after the temperature change and continues for 8 to 10 hours often reaching a maximum of 30 to 40 UOE. The nature of this long-time drift depends on the particular instrument and may be either positive or negative. The experiments described above using end blocks of different materials and with optical bars mounted in various ways showed that the short-time shift of 10 UOE is produced by a change in the angle of the penta-reflector, while the long-time error results from strains in the optical bar produced by stresses transmitted through its supports. This might be expected since the penta-reflector mount is the same in all height finders and any errors arising from it should be the same in all instruments. On the other hand, mechanical stresses transmitted to the optical bar through its mounts will depend on the position of the optical bar in its mounts, and hence may vary from one height finder to another.

These several studies on temperature effects on penta-reflectors and optical bars are gathered together in a Report to the Services issued by the Fire Control Division of NDRC. (41) Inasmuch as no further research in this field is contemplated, this may be considered as a final report on these matters from this source.

Chapter 6

POWER AND BASE LENGTH

6.1 MAGNIFICATION

A comparison of 12 and 24 power in ranging on fixed targets is reported by the Fort Monroe Princeton Laboratory. (344) The purpose of the study was to determine the comparative reliability of range determinations at the two powers provided in the M1 and M2 Height Finders; the comparative reliability of internal adjuster readings at these different powers and the net correction to RCS (Curve B) at different powers. Six experienced observers and three M1 and one M2 instruments were used. The results show that the ratio of 12-power discrepancy between duplicate readings to that of 24 power, over the test period of almost a month, was about 1.10. No significant corrections between the ratio and the individual man, the particular target, or the day could be established. The reliability of internal adjuster readings appeared to be about the same for both powers. This is somewhat surprising; it appears to indicate that factors other than pure visual perception of angles play an important part in the internal adjuster setting. Also, for most observers, the net correction to RCS is about the same for 12 as for 24 power. However, two of the better observers showed considerable difference between 12 and 24 power: the size of this difference was opposite for the two men. No explanation of this anomalous behavior is advanced.

Another set of experiments was performed by the Princeton Laboratory at Fort Monroe using aerial targets. (359) Height readings were taken on aerial targets with six standard M1 Height Finders using four combinations of power and aperture. Magnifications of 12 and 24 power were combined in all possible ways with 1-inch aperture and the normal 2.5 aperture of the wide-open instrument. Consistency at reduced aperture was found to be much better than at full aperture, using either 12 or 24 power. Precision with 24 power was not twice as good as that with 12 power, which ratio is theoretically expected when the observer's sensitivity is the controlling factor. These findings agree with those already noted for ranges taken on fixed ground targets using reduced power or reduced aperture separately. For example, with 1-inch aperture the average precision errors were 2.7 UOE for 24 power and 3.2 UOE for 12 power, and for the full-field instrument, 2.7 UOE for 24 power and 4.1 UOE for 12 power. The consistency errors were, for 1-inch aperture, 5.4 UOE with 24 power and 8.5 UOE with 12 power and, for the full field, 5.4 UOE at 24 power and 3.9 UOE at 12 power. Thus, the observer consistency is markedly worse than when both power and aperture are reduced. This is the combination giving an especially short eye distance, the distance of the exit pupil from the ocular.

The results of these two experiments are presented in a unified report of the Princeton Laboratory at Fort Monroe with the addition of other material on fixed targets. (366) The analysis shows that the precision, measured in yards of error, of readings taken with the M1 Height Finder was substantially better at 12 than at 24 power for range observations on fixed ground targets and was substantially better at 24 than at 12 power for height observations on aerial targets. The relative precision of observations taken at the two magnifications varied greatly from observer to observer, but not from instrument to instrument nor for different target distances. The ratio of precision error in yards at 12 power to that at 24 power, for the 35 observers in this test, ranged between 0.40 and 1.36 for fixed targets and between 0.64 and 3.67 for aerial targets. These ratios for the middle 19 of the 35 observers ranged between 0.63 and 0.90 for fixed targets and between 1.17 and 1.73 for aerial targets. The average ratio was 0.79 for fixed targets and 1.47 for aerial targets.

This document is attached as supporting data to a Report to the Services issued by the Fire Control Division of the NDRC. (19) The experimental data indicate that, under none of the circumstances tested was the precision error at 12 power, when measured in yards, twice as great as at 24 power, as would be predicted from the simple theory of geometrical optics. On aerial targets the ratio was more nearly 1.5; perhaps slightly greater at short ranges and slightly less at long ranges. That is, only about half the theoretical advantage of 24 power was realized. On fixed targets the ratio was actually less than 1; that is 12 power gave more precise readings in yards than 24 power. This was unexpected and the reason for it is not definitely established. It is probably associated with the atmospheric conditions at the

time of the tests, though the subjective judgments of the conditions as noted down by the experimenters do not support this inference. However, if there were heat waves or atmospheric boiling between the instrument and the ground target, this would be magnified greatly when 24 power was used and well might affect the results. The possibility is suggested that an intermediate fixed power (say 18) might be preferable to the present variable power. The evidence is not conclusive enough, however, to justify a recommendation to that effect.

To test this suggestion further an eyepiece assembly with 18 and 36 power was provided and tests were made at Camp Davis by the AA Board comparing the full range of 12, 18, 24, and 36 power. These data have been taken but up to the present (September, 1944) have not been calculated, analyzed, or reported.

The Princeton Laboratory has reported a number of individual studies on power made at Fort Monroe which are largely the basis of their several more formal reports. The first is a preliminary report on the effect of change of power on the spread of range finder readings on fixed targets. (462) The reproducibility of range finder determinations on fixed targets with the two powers is reported in another study. (463) Another paper deals with the relation of RCS and power. (464) Were the visual angle alone in control, it would be expected that the standard deviation of settings at 24 power would be half that at 12 power. Such is not the case. Indeed the question may be raised as to whether there is any evidence that the ratio differs from unity. Of some 15 ratios for 8 observers only one is statistically significantly different at the 5 per cent level. There is a preponderance of ratios greater than 1—12 out of 15. The range of the ratios runs from 0.68 to 1.32. Another study, dealing with net correction to RCS as effected by power, indicates that five of the seven observers show substantially the same net correction for both 12 and 24 power. (465)

A preliminary study is reported on the comparison of 12 and 24 power on aerial courses, which gives in more detail the aerial data summarized above. (466) A final Fort Monroe Princeton Laboratory report deals with the effect of power on the stability of range readings on fixed targets. (467) Here it was discovered that the average of the mean absolute deviations was less for 24 power when either clear visibility or haze was reported, and less for 12 power when heat waves were reported. It is also pointed out that there may be an instrument factor which makes for either longer or shorter ranges on 12 power as compared with 24 power. All observers read shorter on 12 power on a particular height finder, nearly all shorter on 12 power on another, and nearly all longer on 12 power on a third instrument. It is possible, therefore, that some factor peculiar to the individual instruments may be responsible for a changed level of range readings when the power is changed.

A statistical study of the precision of a stereoscopic range finder upon the magnification employed is reported by the Applied Mathematics Panel of NDRC. (66) The data utilized in this study consist of acceptance-test records available in the files of the Naval Inspector of Ordnance-Optical Materials. The records utilized related to instruments manufactured by the Bausch and Lomb Optical Company and those by Keuffel and Esser Company. In each instance, the records were those of the tests carried out by the staff of the Naval Inspector of Ordnance and are not the inspection records of the company's inspectors. The present analysis deals with the records of the Mark 45 Stereoscopic Range Finder and involves the inspection data on 39 instruments. The results indicate that the precision of the instrument when 24 power was employed to the precision when 12 power was used was in the ratio 1.22 to 1. According to the theory of geometrical optics, these precisions should be in the ratio of 2 to 1. Thus it would seem that under the observing conditions at the Bausch and Lomb plant, an increase of magnification from 12 to 24 power resulted in an increase of precision which was roughly one-fifth of the increase expected from the theory of geometrical optics.

6.2 BASE LENGTH

Another report of the Applied Mathematics Panel of NDRC is concerned with the dependence of the precision of stereoscopic range finders on base length. (67) This again is based on a statistical analysis of acceptance-test records for stereoscopic range finders varying in length from 18 to 46 feet. The analysis suggests that, under acceptance-test conditions, the precision increases with base length. The rate of increase seems to depend on the observer to a certain extent. However the results again indicate a breakdown of the theory of geometrical optics, according

to which the precision of a stereoscopic range finder should be proportional to the base length. From an examination of the inspection records relating to the Mark 45, Mark 37, Mark 46, and Mark 52 Stereoscopic Range Finders, which have base lengths of 18, 26.5, 43, and 46 feet respectively, it appears that the precision is not up to theoretical expectation.

A laboratory study at Harvard University was made under laboratory conditions in which it was found that the full theoretical effect of neither magnification nor base length was realized in actual observation. (267) The readings in this study were all on fixed targets under artificial, but excellent, laboratory conditions.

6.3 EFFECT OF MAGNIFICATION ON STEREOSCOPIC ACUITY

Further experiments at Harvard University have to do in part with the problem of magnification and its effect on stereoscopic acuity. (283) These are summarized in some detail in Chapter 2, Fundamental Studies. Both laboratory and field studies were conducted—the latter over both land and water. Magnifications were employed from 1x (the unaided eye) to 40x. Ranges varied from 50 yards in the laboratory to 6,400 yards over water. The results of all of these studies are similar. The relation found between magnification and stereo acuity indicated that the angular error at the eye was not constant, but increased in direct proportion to the increase in magnifying power. Expressed in per cent units ($=100\text{x}\triangle R/R$) the error was constant and independent of magnifying power. Moreover, the per cent error of the observations was unexpectedly low. For any of the ranges or magnifying powers employed, the average mean – variation and the mean – variation of the average adjustments was always less than 1 per cent. Experiments leading to the explanation of these findings are summarized in Chapter 2.

Chapter 7

CALIBRATION OF RANGE FINDERS

7.1 INTRODUCTION

Most of the range and height finders in service at present are provided with adjusting systems designed to correct for any changes in optical alignment which may occur after the initial assembly and adjustment. These changes may be caused by movement of lenses in their mounts, by bending of the optical bar under stress or even temperature conditions, or by other causes. The method of adjustment depends essentially on the use of an artificial target provided within the instrument and designed to appear at infinity when the instrument is in proper optical alignment. An adjusting wedge is provided so that the alignment may be corrected as necessary. These adjustments must be made quite frequently under usual conditions and any errors made in these settings are reflected directly in subsequent range and height readings.

7.2 VARIABILITY OF RANGE CORRECTOR SETTINGS

During the work of the Princeton Laboratory at Fort Monroe a considerable mass of data was acquired which indicated how the Range Corrector Setting [RCS] varied during a series of observations and how inaccurate these settings were when made by student or even expert observers. A number of studies (376, 377, 378, 379, 380, 381) indicate that these RCS readings are not consistent either as to the means or the variances. In most cases, 10 RCS readings were made by each observer on each instrument before range finding readings were taken and a similar number of RCS readings were made by each observer following his ranging. These two sets of 10 readings for each man-instrument combination were examined for differences of means and variances. The set of variances for each man on all instruments was tested for homogeneity. In one case (376) it was found that 12 out of 25 pairs of means differed significantly. Five of the 12 pairs were from a particular instrument. Four out of 25 pairs of variances were found to differ significantly. Neither the entire set of variances of RCS readings before ranging, nor the entire set of variances of RCS readings after ranging, was homogeneous. Only two of ten observers obtained sets of variances on all instruments before ranging which were homogeneous and two men obtained homogeneous results after ranging. Only one observer gave homogeneous results both before and after ranging.

In another experiment (380) two groups of five teams observed alternately for a total of eight courses, each group observing on four courses and each team observing on the same instrument. Each team made 10 readings for RCS start and finish using the same type of contact throughout. The results indicate 25 out of a total of 40 pairs of means showed that the RCS finish was significantly different from the setting of RCS at the start of the courses. Of these 25, 15 had the larger mean on RCS finish. Two observers showed significantly different means on all four courses while only one observer showed no significant difference in means for any course.

These results were obtained in spite of the fact that only one of the ten observers obtained variances for RCS start and finish which were not homogeneous and for this observer this was only true on RCS finish.

The Princeton Laboratory at Fort Monroe has analysed the results of a number of experiments to determine the limits of accuracy of RCS settings and their influence on ranging. In one study it was noted that even the best observer had a standard deviation of 0.75, and the worst a standard deviation of 1.78. From these results the investigators believe that one must expect a standard error in RCS setting of about 1 to 1.25 units. (382) If one assumes that a similar variability will affect a range finder reading, one can say that the minimum standard deviation to be expected in such ranging determinations would be of the order of 1.4 to 1.7 UOE, using the procedure of an RCS determination by the observer before each ranging determination. Another study had to do with variation of RCS due to observer, instrument, and method of contact but the results are not clear-cut and are difficult to interpret. (383) Another report considers RCS settings, namely, net correction to RCS under constant temperature. (384) Two expert observers and two instruments were used. The data obtained were similar to those characteristic of former experiments. It appeared that

both instruments gave a positive error—of 20 UOE and 10 UOE respectively—although both were given a wedge check just before the start of the experiment.

7.2.1 Factors Affecting RCS Accuracy

Another Princeton Laboratory report deals with the influence of errors in RCS on ranging errors. (385) This study was made before the full complexities of the temperature problem were realized. The mean change in RCS per degree F change in ambient temperature for four instruments was found to vary between –0.40 and –0.83, with standard errors varying between 0.15 and 0.27 scale divisions. One M2 instrument differed considerably from the three M1 instruments, a difference which is believed to be due to differences in construction. A further analysis of instrument and observer differences will be found in another report. (386)

The effect of internal target position on RCS is reported. (387) Five target positions of the internal adjuster target of an M2 instrument covered the distance on the reticle pattern from the two small pegs to the left of the center post to the two small pegs to the right of the center. When the central setting was used, the two lines of the target fell one on each side of the center reticle mark. Three subjects made observations—each making 200 readings during a single morning. All settings were made with the target approaching the observer on the last movement of the permitted bracketing. It was found that the average scatter for the central positions was less than for each of the other target locations for all observers. For individual observers, however, other positions were often as effective. The average differences are not great, however, being 55.06 for the central position and 54.42 and 56.31 for the two extreme positions of the target. It is pointed out that the use by an observer of any target position other than the central one in determining the RCS introduces an additional factor in Curve B, but this factor will be constant from day to day only if the adopted target position is likewise constant.

A comparison of binocular and monocular RCS settings is reported by the Fort Monroe Princeton Laboratory. (388) An M2 instrument equipped with collimator scale was used. Four observers were used. Significant differences were found for the binocular and the monocular procedures, right and left eye. It was found that the observer who brings the target nearest for RCS binocularly moves the collimator knob less establishing the monocular enclosure when either the right or left eye is stimulated. The final short study reported by this group has to do with the accuracy of single RCS determinations. (389) Pairs of observers on four instruments gave standard errors which ranged from 0.90 to 1.67 UOE. It should be noted that the values of both observers with an M2 instrument were larger than those of any of the other six observers with three M1 Range Finders.

As a result of these experiments, the Princeton Branch of Fort Monroe suggest the use of external targets as the basis of making range finder adjustments. (348) It makes specific suggestions for the modification of present range finders which, it is believed, should lead to a considerable improvement in their overall performance by the substitution of an external adjuster system. It is unfortunate that in the instruments now in service the internal target is so different from the one the observer is concerned with under combat observation. Of course, this is necessarily true of any artificial target. The system suggested would permit the use of external targets of unknown range in making the infinity adjustment. To accomplish this it would be necessary to remove the internal adjuster system except for the adjuster wedge and the penta-prism assemblies and to replace the right penta-prism by a prism which would split the beam, permitting one half to pass through the right optical system in the usual manner, reflecting the other half at a right angle along the present internal adjuster path so as to pass finally through the left optical system. The infinity adjustment would be made, using any external target desired or available, by setting the adjustment wedge so that the range reading for this target is infinity. This procedure is simply the "known range" method where the target provided is at infinity. This external adjuster method does not immediately eliminate all of the faults of the usual internal adjuster system. For example, refractive errors due to temperature gradients in the gas with which the instrument is charged will persist. The following advantages are claimed for the proposed system: (1) The adjustment is made using the same criterion for the stereoscopic setting of adjustment as is used while actually ranging, thus eliminating all personal and instrument errors caused by the peculiarities of the particular observing conditions encountered at any time. (2) Any external target may be used for practice and training with the range finder without need

for triangulation of target course to determine the quality of the observer's performance. (3) The production and assembly of instruments would be simplified by the elimination of the present rather complicated internal adjuster system. (4) The proposed system may be used equally well with coincidence, ortho-pseudo and direct stereoscopic and other types of range finders. (5) Relatively simple training instruments may be constructed using the proposed external adjuster method, which simulates the range finder task very well.

A final study of calibration of range finders by the Fort Monroe Princeton Laboratory considers the elimination of the need for frequent adjustment of these instruments. (349) This report discusses the instrumental errors inherent in the M1 Stereoscopic Height Finder and proposes the application of range-finding design which would eliminate most of them. The essential notion is that satisfactory precision can be built into a range finder and in such a way that frequent calibration and readjustment will not be necessary. This report presents a principle of optical arrangement which offers an important gain in accuracy by excluding those stray effects now merely compensated for by frequent reference to a standard range and introduction of a range corrector setting. The application of this principle involves no new range-finding method and is equally suited to a stereo reticle, coincidence, or ortho-pseudo comparison fields. The M1 Stereoscopic Height Finder, for example, employs an accessory internal adjuster to provide a primary range standard for determining corrections to a working range standard built into the main optical system. Frequent adjustment of the correction value is required because of stray effects due partly to bending of the structure and light rays which form the working standard. This study urges the desirability of arranging the main optical path so that it embodies a working standard as simple and free from stray effects as the best primary standard, thereby obviating the internal adjuster and range corrector setting. Various sources of error and means of eliminating them are discussed.

7.2.2 Precision of Internal Adjustment Settings

The Army Height Finder

The Applied Psychology Panel has released two reports dealing with calibration procedures and errors for the Army and Navy instruments. The first of these is concerned with the calibration of Army height finders. (79) This report presents an analysis of the calibration records of several groups of students in classes at the Height Finder School at Camp Davis. It is pointed out that finding the right calibration correction to use is one of the most important jobs a new operator must learn. The height finder is so constructed and the theory of its operation is such that an observer who is highly skilled and keeps his instrument in perfect adjustment is able to measure true heights of aerial targets, true ranges to aerial targets, or true ranges to ground targets using the same calibration correction for all three conditions of observation. The records of students at the Height Finder School show that a good student with 11 weeks of training on stereoscopic trainers and height finders makes good height or range readings on aerial targets using the same calibration correction. His error of height readings increased when he used a fixed target calibration correction for aerial targets instead of a specially determined aerial target calibration. They increase by a factor of at least 3 if his instrument is in poor adjustment and by a factor of about 2 when his instrument is in good adjustment. This error can be reduced still further by practice in stereoscopic observation on both ground and aerial targets. In one winter class it was found that the optimal corrections for fixed targets and for aerial courses differed by 4 UOE for 70 per cent of the men. The average difference for the 37 men was zero. These findings apply equally to the use of the "known range" method or the use of a celestial target in making his calibration correction. These results lead to the following recommendation. The Army Height Finder School uses a special calibrating procedure which allows the student to determine on aerial target calibration correction by comparing his readings with target position data obtained by a target Practice Record Section using phototheodolites. To emphasize the importance of proper instrument maintenance and to give men satisfactory training in calibrating the height finder under field conditions, it is recommended that students at the Height Finder School be trained using a calibration correction based on fixed target and on celestial target readings instead of a calibration correction based on Record Section measurements.

The Navy Mark 42 Range Finder

The second report deals with precision of internal adjustment settings of the Navy Mark 42 Range

Finder. (80) Although experienced range finder personnel consider that a series of internal adjuster settings should have a spread of less than 1 UOE, no experimental studies had been undertaken to determine the precision with which Naval personnel actually make these settings. The present research was undertaken to determine the range of internal adjuster settings made by student range finder operators using the usual stereoscopic method at the Fire Control School at Fort Lauderdale. It was found that 18 advanced range finder students made a series of five internal adjuster settings in the course of routine operations with an average range of 2.50 UOE and an average standard deviation of 1.10 UOE. To ascertain whether students make more precise readings in an experimental situation where greater care was used in recording the settings, six men made a series of stereoscopic internal adjuster settings. Although the mean range and mean standard deviation of this experimental group of 6 men were less than the same measures for the 18 men, a significant difference was not demonstrated. In the case of the 18 men the range of means varied from 0.5 to 10.0 UOE and only 5 men had 1 UOE or less while 7 men had 2 UOE or more. An additional portion of the experiment was devoted to a comparison between stereoscopic and monocular methods of making the internal adjustment. A significant difference in precision between the two methods was not demonstrated. Recommendations for training procedures designed to produce more precise internal adjustment by range finder operators are given in detail, indicating the steps to be taken in making a series of 9 settings—the median value to be used as the internal adjustment correction.

A further report by the Applied Psychology Panel, NDRC, is an extension of the previous study. (97) The precision of internal adjustments made by student operators following the revised procedure was measured at various times during the period of training at the Naval Training Station at Fort Lauderdale. In order to establish a standard for comparison and to determine the degrees of precision attained by experienced shipboard range finder operators, records of series of internal adjustments made by such operators were obtained and analyzed. It was found that 81 student operators of Mark 42 Range Finders attained a mean range or spread of internal adjustment settings of 2.27 UOE. This smallest range was reached during the sixth week out of eight weeks of training on this instrument. Learning, as measured by an increase in precision in making internal adjustments, occurred from the first to the sixth week. Twelve experienced shipboard range finder operators, each making 63 to 75 series of internal adjustment settings, obtained a mean range of 1.37 UOE. This figure is of significantly greater precision than that obtained by the student operators. The revised procedure in making internal adjustments enabled the student operators to increase the precision with which they made the settings. In view of these experimental findings, the investigators recommend that additional stress be placed upon internal adjustment setting procedures and that measures be taken to increase motivation with regard to this adjustment. The settings should always be measured at least to the nearest 0.25 UOE. Motivation might be increased by periodically posting, in a conspicuous place, the range or scatter of series of internal adjustments made by all the student operators in a given class.

The Applied Psychology Panel reports an experiment carried on at the Fire Control School at Fort Lauderdale, Florida, comparing five methods of calibrating the Mark 42 Range Finder. (89) A range finder operator must compensate for his personal error in ranging by applying a calibration correction to his instrument. Only by so doing can he be expected to obtain accurate ranges. There are a number of methods by which an operator can obtain his calibration correction. This experiment was designed to compare the magnitude and precision of calibration corrections obtained by as many methods as were feasible at a shore installation although every attempt was made to duplicate, insofar as possible, the way in which these methods would be used aboard ship.

The 12 best operators in a training class obtained calibration corrections by ranging with the correction knob on celestial targets: a star, the moon, and on a fixed target of known surveyed range; with the correction knob method and with the range knob; and by ranging on an aerial target simultaneously with fire control radar. Also calibrations were made by ranging with the correction knob on the sun when its brightness was reduced by rhodium mirrors fitted over the end windows.

The following results were derived from a statistical analysis of the data. The magnitudes of the calibration corrections obtained by each of the methods

do not differ significantly from each other. The methods rank as follows in terms of precision: (1) known range method (correction knob); (2) known range method (range knob); (3) celestial star target, celestial sun target and radar method. When operators are given sufficient practice in the use of the celestial target methods, their precision should approach that of the known range methods. It is pointed out that, in terms of adaptability to shipboard conditions, the celestial target methods and radar method are superior to the known range methods. The report recommends training in all these methods with an emphasis on greater proficiency than has been required hitherto. It is also recommended that rhodium mirrors or suitable filters be provided for all range finders to make possible the use of the sun as a celestial target.

7.2.3 The Internal Adjuster Target

Single and Parallel Bars

A number of studies have been made of the artificial target employed in the internal adjuster system of range finders. One study by Ohio State University was a direct experimental attack upon the question of the accuracy and precision of internal adjuster settings, using a single bar or the present double bars as the reticle to which the diamond target is to be stereoscopically adjusted in the Naval instruments. (324) It was found that so far as precision of settings is concerned, there is essentially no difference between using two bars and using one—average values being 0.442 and 0.425 UOE respectively. There was some indication in the results that tilting of the horopter causes a constant error in the average settings of the diamond when a single bar to the right or left was used as reference point, but is not manifest in the case of the two-bar target. The error arising from this source was found in one case to be approximately 0.447 UOE. Data from a limited number of cases indicate that better results are obtained using black figures on a light background than white figures on a dark background. The results of several subjects who failed to make precise settings showed a marked tendency to set the diamond at a considerable distance in front of the bars. The explanation of this effect was not discovered, but it points to the conclusion that large constant errors can be expected if the subjects are not able to make precise settings, and that these errors will, in general, be in the direction of setting the diamond in front of the target bars in order to make them appear in the same place.

Vertical Line and Other Patterns

A series of experiments dealing with reticle and artificial target patterns for the internal adjuster was made by Brown University. In the first of these reports five patterns for use in internal adjusters for monocular instruments were tried and one was found to be superior to the other four for both experienced and inexperienced observers. (139) This pattern, which consists of a longer vertical line to be placed so that it bisects the space between two smaller vertical lines, yields more precise and more consistent range corrector settings. With this pattern and under favorable conditions, an average experienced observer is able to maintain a level of precision which is represented by an average deviation of 3.2 seconds of arc, or 0.27 UOE from the mean of his own settings. Under similar conditions, this pattern yields a consistency of mean settings from observer to observer as represented by an average deviation of 3.2 seconds of arc or 0.27 UOE from the mean of all settings made by a group of observers under comparable conditions. Inexperienced observers are nearly as consistent as experienced ones and the practice effect from the first to the second day of experimentation is negligible or nonexistent. With this pattern the mean average deviation of 25 inexperienced observers was 0.31 UOE as compared with 0.27 UOE for the experienced observers as noted above. This pattern has an accuracy and a consistency at least 20 per cent or more better than any of the four other patterns which were centering a dot inside a circle, bisecting with a vertical line the space between two diamonds, bisecting an open diamond with a vertical line, and bisecting a circle with a vertical line. Finally the superiority of this best pattern was maintained over most of the range of useful brightnesses for the light-adapted eye from 0.3 to 30 millilamberts.

The second Brown University experiment is a more complete study of two patterns—the fiducial line between the target of two vertical lines and between two target diamonds—under six levels of illumination varying from 129.0 to 0.033 apparent footcandles. (142) It was found, for both types of target, that precisions are poor at low illuminations and

become better as the light intensity increases. The target line proved to be superior to the diamond target at all but the very lowest level of illumination.

In an additional Brown University experiment, using only the vertical line target, an attempt was made to determine the effect of the separation of the two vertical target lines which determine the space to be bisected by the fiducial line. (143) Six separations were employed equivalent to angular separations of 5.5 to 22.1 minutes of arc respectively, all the lines remaining at 5.5 minutes of angular width. The results show that precision is greater for the smaller separations and precision decreases approximately linearly as the separation between the target lines increases.

These experiments were made with a testing apparatus devised at Brown University to study internal adjuster settings of either the monocular (vernier) or binocular (stereoscopic) types. This apparatus is described in detail. (158) When comparable visual patterns were used for stereoscopic and monocular performance, monocular settings were made with somewhat greater precision and with smaller constant errors than stereoscopic settings. In another series of experiments at Brown University, it was found that the highest precision was obtained when a vernier bisection method was used with monocular vision on an internal adjuster pattern involving the centering of a vertical line between two fiducial lines. (159) As a result of these experimental findings, the investigators suggested that the precision of internal adjuster settings may be increased over the present method by employing monocular observation, as in the so-called Abbé internal adjuster system, instead of attempting to make stereoscopic settings. Greater constancy of settings between observers was also found for the monocular system. It is pointed out that, besides the fact that the Abbé system gives greater precision of setting the internal adjustment of the instruments, its adoption would have other advantages. These include: (1) utilization of the normal path for internal adjuster settings; (2) considerable reduction in the number of optical parts required; (3) simplicity of construction; (4) relatively greater clearness of the internal adjuster target images; and (5) less susceptibility to the effects of temperature and other external influences. Two possible schemes for applying these findings in the present types of range finders are indicated. One of these involves placing internal adjuster targets on the existing reticles used for ranging; the other involves a vernier setting on the present unchanged reticles of the Army M1 and M2 Height Finder instruments.

These five documents are attached to a Report to the Services issued by the Fire Control Division of NDRC. (31) This report makes the following recommendations: (1) The adoption for monocular range finders, particularly of the short base type, of an internal adjuster pattern which involves setting a fiducial line midway between two target lines; (2) The introduction of a monocular type of internal adjuster system into one of the present stereoscopic range finders, both laboratory and field tests to be given this modified instrument. The Naval Bureau of Ordnance had this modification made in a 1.5-meter stereoscopic range finder by having the Naval Gun Factory remove the normal internal adjuster system and introduce the Abbé system of calibration. This modified instrument and a normal instrument have been sent to Brown University for comparative study.

Brown University has completed one more study which embodies the results of a further analysis of the precision of range corrector settings for small monocular range finders. (136) There were 6 experienced and 25 totally inexperienced operators and three brightness levels of illumination were used. Only two patterns were used, namely, placing the vertical fiducial line midway between two target diamonds or two smaller vertical target lines. The results are the same as before, showing a higher degree of precision and better agreement among observers for the line target pattern. This is true for both skilled and unskilled observers and for three degrees of brightness (from 0.3 to 30 millilamberts). Even with unskilled observers the distribution of mean settings on this pattern shows an average deviation of less than 0.3 UOE from one to another.

Chapter 8

MISCELLANEOUS INSTRUMENT AND OPERATIONAL DEFECTS

8.1 INSTRUMENTAL CAUSES OF RANGE FINDER ERROR

8.1.1 Penta-System Rotation

A FORT MONROE PRINCETON LABORATORY report discusses the height finder errors which might be caused by penta-system rotation. (513) This may occur in any one of three planes. The report presents the hypothesis that a certain type of distortion may be expected in a height finder which would introduce range errors in the top and bottom of the field. There is a small amount of experimental evidence that such errors actually occur. The paper also contains the calculation of the associated second-order effects. The only first-order effect occurs with rotation about one particular axis and would produce an apparent slant back or forward in the stereo position of a vertical object. This effect would amount to 0.0204 UOE disparity at top or bottom of the field for 1 UOE rotation of the penta-system with 24-power magnification. At 10,000 yards range a rotation of the image in the field of 0.018 degrees would produce a range error of ± 100 yards. It is believed that such play in the penta-systems is possible in field service.

8.1.2 Type of Filter

An experiment run at Fort Monroe and reported by the Prinecton Laboratory indicates that real differences in performance with different filters, under ordinary atmospheric conditions, are probably not more than 2 UOE in size, if they exist at all. (468) Five filters are available in the M1 Height Finder; clear, amber, red, dark, and blue. There is a slight indication that the use of a clear filter (the filter most frequently used) may result in a somewhat smaller consistency error than results from the use of the other filters. This effect is about 1 UOE in magnitude, a reduction by a factor of nearly 2. There was no evidence of any other filter effects. These conclusions are based upon 60 range observations with each of the five filters by two experienced test observers.

8.1.3 Leveling and Alignment

A theoretical study of the severity of the systematic height and range errors in an M1 Height Finder as a result of known leveling and alignment errors is reported by the Princeton Branch of the Frankford Arsenal. (243) The memorandum discusses the problem of alignment and index errors in this instrument, with particular reference to the required accuracy of leveling and wedge-check agreement and to the desirable changes in specifications and field procedures. The conclusions apply immediately to any 13.5-foot base, 24-power height finder used with a data transmission system of accuracy comparable to that used in the M1 Height Finder, provided height is not read below 200 mils angular height or 550 yards height. The conclusions may be easily modified to apply to any height finder using a height-conversion mechanism similar to that used in the M1 instrument. The following conclusions are made on the basis of the theoretical calculations:

1. Since the angular height of an aerial target is determined by pointing the elevation elbow telescope, the line of sight of this telescope should be precisely level when the alignment of the wedges is checked.

2. If the difference between the range-infinity and height-infinity settings is not to be readjusted, then the resulting errors are minimized (a) by making the height-900-yards and range-infinity settings, rather than the height-550-yards and height-infinity settings, coincide when adjusting the height-conversion mechanism, and (b) by making the internal adjuster setting with the range-height lever in the height position and the height finder proper elevated to 650 mils.

The following recommendations are made.

1. The total movement of the fine elevation adjustment shall not be less than 1 degree of the true field.

2. With the horizontal reticle line in the elevation elbow telescope falling on an established level line and with the tripod and cradle level, fine adjuster settings each shall be made at height-infinity, and at height-900-yards. The medians of these two sets of

readings shall differ by less than 2.0 UOE. The medians at range-infinity and height-900-yards shall differ by less than 1.0 UOE.

3. Set the microscope on the elevation scale to read 0 degree when the range-height lever is at the height position. When the lever is moved to the range position, the elevation angle shall be 90 degrees ±30 minutes.

4. When the horizontal reticle line from the elevation elbow telescope falls on an established level line, the horizontal reticle line in the azimuth elbow telescope shall fall within 2 minutes of this line and the level bubble on the height finder proper shall be within 0.5 division of the center of the scale.

5. When the horizontal reticle line in the elevation elbow telescope falls on an established level line, the fine elevation adjustment shall place the center lines of the main reticle marks at least 24′ above and below the established level. It is believed that these modifications will ensure more accurate range and height readings in the field and also make the specifications easier for the manufacturer than those then existing. The use of the relation of the elevation elbow telescope to an established level line, instead of the use of the level on the heightfinder proper, to determine the correct elevation or depression of the heightfinder is deemed important. It is also recommended that consideration be given to the design of a suitably portable instrument permitting the simple and rapid establishment of an actual or artificial level line for the elevation telescope.

This last recommendation is considered further in a subsequent report of the Princeton Branch of the Frankford Arsenal which presents a design of a simple optical instrument for accurately leveling the line of sight of the elevation tracking telescopes of height finders, directors, and optical trackers and gives a summary of the instrument's performance when used to collimate the elevation tracking telescopes of the M1 Height Finder. (257) This instrument is described in the text and sources of error are discussed. To test the level collimator, it was mounted on the elevation tracking telescope and a level point was provided by sighting the azimuth tracking telescope on the reticle grid of a transit. Repeated level settings were made using the level collimator and after each trial the alignment of the horizontal reticle mark in the azimuth tracking telescope was checked against the fixed reference grid of the transit. The reticle graduations of the transit used were such that its accuracy as a calibrating instrument was no better than 1 minute of arc. All level settings using the level collimator were made within the limits of accuracy obtainable with the transit (0.3 mils). Following each level setting made with the level collimator mounted on the elevation telescope, the alignment of the horizontal reticle mark in the azimuth tracking telescope was checked against a grid of known dimensions placed at a distance of 60 yards from the height finder. By stopping down the objective of the azimuth tracking telescope to 0.25-inch aperture to eliminate parallax, the inaccuracy of this test technique was 0.5 minutes of arc or 0.15 mils. Repeated determinations indicated that the height finder could be levelled within these limits of accuracy.

8.1.4 Unequal Light Transmission

At the Admiralty Research Laboratory experiments were carried out which demonstrated that false stereoscopic effects were produced in stereoscopic systems where a difference in brightness exists between the two fields of view when there is relative azimuth motion of the target and reticle. (51) In the M1 Height Finder, which has light transmissions of 19.5 and 13.6 per cent for the two telescopic systems, the time lag between the eyes of the observer is 1/400 second. This has been confirmed experimentally by observations with this instrument. Assuming that the rate of transverse of the height finder may be in error by 10 minutes of arc per second when following moving targets, the presence of a time lag of this magnitude would cause an error in range of 1.5 seconds of arc, or 3 UOE with a 24-power magnification.

8.1.5 Lack of Parallelism of Emergent Rays

A study of the effect of lack of parallelism, in the vertical meridian, of the emergent ray in an M1 Stereoscopic Range Finder was studied experimentally by HMS Excellent. (302) The effect was produced by placing a prism base up over one eyepiece and another equal prism base down over the other eyepiece. In this way errors were produced as great as 60 minutes of arc of apparent field in the height of the two presentations, both reticle and target. This is not to be confused with height adjustment of target and reticle. It was found that even so

large a lack of parallelism does not produce any significant falling off in precision as measured by mean consistency (scatter of observations about the mean). It was found that there was no falling off of consistency under these extreme conditions even after the observer had been fatigued by continued ranging. It is considered that lack of parallelism of emergent rays in this amount fails to cause a falling off in consistency because the range taker can partly compensate for the discrepancy by tilting his head, so long as the tilting is not so great that the eye cannot see through the exit pupils of the range finder. The conclusion is reached that the manufacturing tolerance of ± 18 minutes of arc of apparent field is adequate.

8.1.6 Backlash

The Applied Psychology Panel report a study of backlash between the main bearing race and the bevel pinion in the M1 and M2 Height Finders. (69) Very little attention had previously been given to backlash between the main bearing race and the bevel pinion of M1 and M2 Height Finders as a possible source of error in height measurements. The presence of backlash in this mechanism is of considerable importance because the present wedge inspection procedures and wedge adjustment tolerances are based on the assumption that backlash is absent between the bevel pinion and the main bearing race when the height-range level is put in the height position. Three different procedures were used in measuring the amount of backlash in eight M1 and two M2 Height Finders. The results show that the amount of backlash is often very large. Its presence results in short height readings on incoming aerial courses and long height readings on outgoing aerial courses. The report recommends inspection and reduction of such backlash in all instruments.

8.2 ERROR STRUCTURE OF RANGE AND HEIGHT FINDER

A report from the National Bureau of Standards theoretically analyzes the kind of errors which may be expected in the operation of a range or height finder. (322) These errors may be either of the systematic or accidental type. They fall into four general classes: (1) external errors—those which originate in the atmosphere lying between the target and the instrument, (2) internal or instrumental errors—all errors originating within the instrument, many of which can be eliminated or ameliorated by modification of design and construction, (3) physiological errors or those which arise from the performance of the eye as an optical instrument, and (4) psychological errors or all errors that originate beyond the retina. Although any and all of these errors may seriously affect the accuracy of an individual reading, it is pointed out that when the range finder is used in connection with a director, the readings are used to determine the time rate of change of range and their effects are somewhat decreased.

8.2.1 Psychological Error

On the basis of this analysis, the National Bureau of Standards reports a quantitative study of one type of error of the psychological sort. (323) It has often been assumed that readings made with the stereoscopic range or height finder might be affected by a psychological bias, different for different observers or for the same observer on different targets, which causes settings to be inaccurately made and introduces range errors that are independent of the instrumental accuracy. The test of a captured German range finder (Type R 40), which is provided with means for making observations with ortho or with pseudo stereoscopic viewing, enables this error to be measured. The values obtained are surprisingly large and of considerable importance. All tests were made on terrestrial targets. The instrumental performance of the R 40 Range Finder is excellent, instrumental errors amounting to no more than plus or minus 1 second over ranges varying from 19,000 to 1,400 yards. Nevertheless, experienced observers frequently make errors as large as 2 seconds and, on one target, an error of 5 seconds was made because of psychological bias. For this particular instrument, 5 seconds correspond to 15 UOE. Psychological errors of this kind may be sufficiently systematic to be partially compensated for by the uniformity of targets when a height finder is used against planes, or for use against naval targets. Such compensation does not appear practical for terrestrial targets. There are reasons for believing that this psychological error may be even greater for the M1 Height Finder than for the captured German instrument.

These results lead the author to suggest the following considerations: (1) In estimating the quality of performance to be realized in a stereoscopic range finder for use in a tank or by the field artillery against terrestrial targets, the possibility of an error due to psychological bias amounting to 2 or more seconds should not be overlooked. (2) The coincidence or vernier type range finder should not be abandoned too hastily. It is probably less subject to this psychological error than is the stereoscopic type. In this connection, it should be noted that the development work at the National Bureau of Standards is proceeding along parallel lines with the stereoscopic and vernier types of instruments. (3) The ortho-pseudo stereoscopic instrument assumes increased importance not because of its doubled sensitivity but because it is possibly free, or relatively free, from errors arising from psychological bias.

PART II

THE MAN-INSTRUMENT COMBINATION

THE FOUR chapters (Chapters 9 to 12) deal with the range finder when used by a human operator. It has been found that the range finder, under the best operating conditions, seldom if ever gives results whose accuracy, precision, or consistency closely approach the theoretical expectation of the instrument itself. These four chapters deal with experiments which seek to isolate the causes of such discrepancies due to the operator and his manipulation of the instrument.

Chapter 9 deals with certain psycho-physiological factors of the operators. The results are largely negative because it was found that fatigue, lay-off, loud sounds, and sex differences were relatively unimportant. Although some of these factors seem to be effective, as for example severe fatigue, it was found that if the operator could be sufficiently highly motivated, he could seemingly lift himself by his bootstraps for a short time and give as good ranges as in the unfatigued state. Drugs were applied with two goals in view. It was found that the administration of benzedrine sulphate showed slight advantage in overcoming drowsiness and that metrazol, a cerebral and respiratory stimulant, had no significant effect on the variability of range estimates in normal operators.

Chapter 10 deals with experiments having to do with the relative position of reticle and target. The results show that the so-called height-break is of great importance for accurate ranging. This is the failure to adjust the target properly and the reticle pattern correctly. Hence, although in some instruments the range finder operator has control of a fine height adjustment system, these studies emphasize the importance of tracking so that the target image may be kept in the correct position with regard to the reticle. Fundamental experiments dealing with the analysis of factors for improved tracking mechanisms and others studying reticle designs which will reduce the effect of this misalignment are summarized.

Chapter 11 deals with fundamental laboratory studies of the effects of haze and of atmospheric scattering. Although the results indicate that such atmospheric effects are reflected in the accuracy of range measurements, it is now considered that these are less important, in field practice, than was formerly believed. The experiments show that difference in contrast between the target and its background is the important variable in this situation.

Chapter 12, the final chapter in this group, deals with miscellaneous factors of operation, such as techniques for maintaining stereoscopic contact between target and reticle, focussing of the telescopic eyepieces, and the use of the range finder as a spotting instrument.

Chapter 9

PSYCHO-PHYSIOLOGICAL FACTORS OF OPERATORS

A SERIES of studies were made to determine the effects of certain psychophysical factors of stereoscopic operators upon the accuracy and variability of ranging. Many of these results are summarized in a Report to the Services issued by the Fire Control Section of NDRC. (12) Some of the material included in this report will not be found elsewhere. This chapter deals with carefully controlled experiments performed in a number of research laboratories.

9.1 SOME BASIC STUDIES

At the Harvard Fatigue Laboratory it was found that the angular limits of binocular fusion increase as the angular size of the target increases. Four subjects made observations with a specially devised apparatus. (269) The amounts of the fusion limits are of considerable extent, being doubled when the target size is increased 16-fold. All of the curves are of similar form for all four subjects—starting with low fusion limits for small target size, increasing rapidly and then more slowly as the target size is increased. This result raises interesting questions concerning the use of binocular retinal disparities to occasion changes in apparent distance by means of stereoscopic instruments which purport to measure range accurately. For example, as the angular size of the target increases and thus, as the angular range throughout which disparities are effective is increased (1) is each "unit" of apparent distance magnified, i.e., multiplied by a constant, or (2) do these units remain constant in size while their number is increased?

In a second study at the Harvard Fatigue Laboratory a study was made of the limits of binocular fusion as dependent upon binocular vergence. (270) It was found that for proximal distances (about 1 meter) and for a given target-reticle assembly, the limits of binocular fusion in angular units are found to be essentially constant. It was important to discover these limits because it is only within such limits that binocular disparities can be effective for normal stereoscopic vision. A specially constructed apparatus was employed (cf. 272 for description) and the same four subjects were employed. It was found that the curves for all subjects were very similar, showing an increase of the fusion limits for disparate images as a straight line relationship with the converged distance. When ocular vergence is fixed, the limits of binocular fusion for any given degree of vergence appear to define the limits throughout which binocular retinal disparities are effective. In this present experiment, the target angle subtended a visual angle of about 1 minute and the range throughout which binocular retinal disparities were effective was found to be constant at approximately 10 minutes of arc.

A third Harvard Fatigue Laboratory experiment had to do with apparent size and binocular vergence. (272) It was found that the apparent visual size of a target is an increasing function of the converged distance. The rate of change in the apparent size of the target with respect to binocular vergence is directly proportional to the size of the target. Qualitatively, this effect is quite noticeable in all stereoscopic range finders, inasmuch as when the target recedes it seems to become larger, which is exactly opposite to the normal effect in unaided stereoscopic vision. The figures for the relation of apparent size and binocular vergence and for the rate of change of apparent size are extremely similar for all four subjects.

A fourth laboratory study of this series, performed at the Harvard Fatigue Laboratory, is concerned with the relation of binocular vergence and target size on apparent distance of the target. (271) The results were obtained from the four observers previously used working with a special apparatus. The results are consistent with the notion that the apparent distance of a target is practically independent of its size. From one observer to the next for any given target size and vergence, and for any given observer, the differences in measurements are randomly ordered with respect to the vergence of the eyes. The angular size was varied from 0.5 degrees to 2 degrees, a ratio of 4 to 1. The variation from one target size to the next for any given degree of vergence lies within the limits of variation usually found when a single target was used. Hence the investigators conclude that the average apparent distance, as a function of the converged distance, or the point in space to which the eyes are converged, appears to be independent of the size of the target for the sizes studied.

At Ohio State University a careful laboratory study

was made to determine the dependence of cyclophoria on eye and head position. (329) It is known that cyclophoria may be produced with changes in eye and head position such as the operator must make to compensate for the turning of the range finder for vertical tracking changes. This might introduce false differences in binocular parallax between the target and reticle when a vertical separation exists between them. The reason for the appearance of such an error can most readily be seen if one considers the situation in which the reticle and target are actually in the same stereoscopic plane, and one is displaced above the other. For the observer with cyclophoria the ocular images of the reticle and target will have a different relative lateral displacement with respect to the physiological vertical meridians of his retinas, and this displacement will be equivalent to that normally introduced by a difference in depth between target and reticle, and would be interpreted psychologically as such. Because of this practical problem and because of more theoretical considerations, a general survey was undertaken of the dependence of cyclophoria on various positionings of the eyes in the orbits and with respect to each other, as well as a preliminary investigation of the dependence of cyclophoria on the position of the head.

Records were taken with a synoptoscope, a haploscope, and a head-positioning instrument, which are described in the text. Nine subjects were used in a number of experiments attacking different variables of the problem. The results indicate, in spite of a considerable consistency of the data on cyclophoria in relation to eye position, as formulated in terms of Listing's Law, individual variations and discrepancies made it impossible to predict cyclophoria changes in general, at least without data on each individual, even under the rigidly controlled laboratory conditions and with subjects trained to make these observations. It therefore seems necessary, and by all odds easiest, to avoid the situation in the range finder by avoiding vertical separation of target and reticle which permits changes in cyclophoria to produce range errors. Failing this, or as a supplement to this attempt, the authors recommend that an effort should be made to keep the target well-centered laterally on the reticle, since this would obviate lateral eye movements, which might induce changes in cyclophoria. Both of these recommendations indicate the need for tracking accuracy. Furthermore, the failure to discover significant changes in cyclophoria with changes in head position indicates that there is no source of error related to this activity in range finding.

An investigation of the interval of time elapsing between the making of a range and the signal that the range has been made was undertaken at the Howe Laboratory of Ophthalmology. (309) A special apparatus described in the text was used and three trained subjects were employed. The situation was a simulated diving target which corresponded to a plane diving from 25,000 feet to 5,000 feet at a constant velocity of 296 knots. Both hand and foot depression of a telegraph key were employed. It was found that the average interval between making a range and report by key tapping of its having been made is about 0.08 seconds. Hence it was recommended that the dead time settings should not be altered because of an assumed interval between the time when range has been made during continuous contact operation and the time when the range finder operator signals that the range has been made. No significant differences in this time interval were found for signal with hand or foot operation.

9.2 FATIGUE AND MOTIVATION

It was suspected that range finding over a long period might result in reduced efficiency due to fatigue and/or monotony. A series of experiments were performed to discover the effects of fatigue or of motivation as it might affect either fatigue or the monotony of the task. Much of this material is summarized in a report from Tufts College. (572) For most of the fatigue tests the situation was made as realistic as possible to simulate a military situation.

In one experiment at Tufts College the modified dynamic Mark II Navy Trainer was employed. The observer was required to track continuously in azimuth an airplane target as it moved in an irregular pattern across the field. (549) A single observer performed the task continuously for 13½ hours. The subject was paid on an hourly basis and, when a decrement in performance appeared, the pay rate was increased in an effort to introduce additional incentives in an attempt to maintain maximum efficiency. In an earlier experiment five subjects performed this task but without special motivation.

In the first experiment, it was found that although continued performance for 4 hours frequently

showed a marked decrement—as an increase in the frequency of large errors—there were great individual differences. One observer who tracked for 4 hours showed no significant decrement whatever. Furthermore, the capacity of a trained observer, as measured by his accuracy during the first 5-minute period of tracking, and his performance during three periods of 4 hours, bore little relation to each other. One subject, however, whose error score varied from 2 to 4 in the first 5 minutes, never exceeded an error score of 4 for the first 3 hours of his first 4-hour period, but never had an error score of less than 7 for the first hour and a half of his third 4-hour period. Another subject, whose error score varied from 5 to 7 during the first 5 minutes, had error scores for his first 4-hour period which only once were less than 19 and error scores for the second 4-hour period which only once were above 14. A striking feature of the decrements induced by prolonged tracking was that they could be offset to a considerable degree by the introduction of various "incidents" such as rests, promised increase in pay, and encouragement in making an effort. These improvements, however, were of very short duration. The investigators demonstrated that a decrement in tracking performance could be produced by long continued activity in the same task and that the decrement may be reduced by adequate motivation but not to initial performance levels and finally that such temporary improvement is short lived. Hence they conclude that in the case of tasks such as azimuth tracking, which do not involve any considerable muscular effort, performance decrement comes from boredom rather than physiological fatigue, though it may not occur at all, or be greatly reduced, if boredom is prevented.

A second experiment at Tufts College involved a 3-day test of fatigue effects under conditions of long hours of duty and limited sleep. (550) This experiment was designed to approximate actual field conditions, where fatigue effects, if they occur, are the result of activities which intervene between the brief periods of actual operation of ranging instruments. Over a 3-day period, a group of four observers was required to work, eat, and sleep according to a highly irregular schedule, with short periods of sleep and long hours of duty. During these periods on duty, the men were constantly on the alert and they were required to record the time of occurrence and nature of certain light flashes which were produced at irregular intervals on the viewed terrain and at distances of 376 to 945 feet from the observers and in an angular field of 30 degrees. The subjects were also required to report at intervals to the laboratory for short tests of stereoscopic ranging and tracking. Although by the end of the test it was evident that the men had been under strain, a comparison of their performance on the various tasks for the first and second halves of the 72-hour period showed no decrement. Hence the investigators conclude from this experiment that decrease of sleep to 16 hours out of 72, combined with alertness for 42 hours out of 72, need not result either in decreased efficiency as a watcher or in decrement of performance in stereo ranging and tracking.

Still another Tufts College experiment had to do with the effects of deprivation of sleep for 50 hours upon stereoscopic ranging performance. (551) Ten observers took part in this experiment and they were tested regularly during this period on both ranging and tracking performance. It is reported that these subjects were exhausted at the end of this 2-day period of wakefulness. However, comparisons of performance during the first 24 hours and the second 24 hours in tracking accuracy indicated no decrement. A similar comparison in regard to stereo range determination showed a decrement in precision, but the magnitude of the decrement was not great enough to be considered a serious factor in affecting accuracy of fire. Certainly the differences were not statistically significant for any one of the 10 observers.

These subjects were also given certain non-military tasks during this period, such as arithmetic, reading rate and comprehension, and steadiness tests. No decrements were found in the scores of any of these measures. On the other hand, from clinical observation of the subjects and from the subjects' own reports, there is no question but that the group was "tired" in the ordinary sense of the term, while not irritable, the observers became increasingly less social, and greatly less responsive. Their conversation was often nonsensical, incoherent, and irrelevant; they grew progressively indifferent to their surroundings, eventually showing a definitely lessened interest in all social activity. They kept their performance records from falling as the experiment progressed by making a greater effort to attend to the tasks.

Still another experiment at Tufts College was concerned with the effects of prolonged strenuous exercise. (553) Two groups of five men were made to march 30 miles, an activity to which they were not

accustomed. Their performance in a number of tasks was tested before and after the march, and also at the end of the first and second 10 miles. The tasks involved were stereoscopic acuity and tracking accuracy, brightness discrimination, reaction times, and persistence at a routine clerical task. Special monetary incentives were used to keep effort at a high level. Although the observers showed unmistakable clinical signs of fatigue, such as sleepiness, slouching, garrulousness and silence, no decrement appeared in their stereoscopic acuity, tracking accuracy, sensitivity to brightness differences and reaction times. The test of persistence, however, which lasted an hour and a half, did show a statistically significant decrement. Hence a decrement in some performance was demonstrated as a result of the fatigue from the hiking activity. However, prolonged strenuous exercise does not seem to affect performance in tasks such as ranging and tracking, provided the duration of these tasks is short and a strong incentive is present. Such fatigue, however, does affect adversely persistence at a task over a period as long as 1½ hours.

Tufts College performed another experiment in this series which had to do with the effects of short-period exercise on stereoscopic ranging. (554) In this experiment, nine well-trained observers were subjected to a period of rapid stair climbing carrying a very heavy load. Immediately following the exercise, they were given a test of stereoscopic range finding, the results of which could be compared with similar tests taken just before the exercise period. The exercise consisted of three trips up and down a 30-foot staircase carrying a 36-pound weight. This was performed rapidly, as the entire exercise lasted only from 87 to 110 seconds. Observation of the subjects' reactions indicated that the effort was extreme. They showed the common symptoms of physical strain and breathlessness, and several remarked that they would be unable to make another round trip. Comparison of the standard deviations of the ranging sittings showed that a statistically significant increase in variability was present after the exercise. The average amount of this increase was about 0.5 UOE. Analysis of the results by groups of ten settings showed, however, that the increase in variability was very short lived, disappearing by the end of 5 minutes.

There is evidence that this decrement is not the result of fatigue but of hyperventilation due to breathlessness. An experiment at the Harvard Fatigue Laboratory on this problem was performed by having the subjects breathe deeply to the rhythm of a metronome set at 32 or 50 cycles per minute. (279) The subject maintained this rhythm until he experienced spells of dizziness or a blurring of the visual field. Immediately following this, the subject made 10 range estimates using either stereo or vernier acuity. The results show a marked and consistent increase in variability which occurs immediately after the hyperventilation. Without exception, the subjects made poorer as well as more variable judgments following hyperventilation. Observers sometimes had difficulty in fusing the reticles for 30 to 45 seconds after hyperventilation. The effects were more pronounced on stereoscopic acuity than they were on vernier acuity.

Another Harvard Fatigue Laboratory experiment had to do with the effects of exercise but without breathlessness. (275) Both stereoscopic and vernier acuities were tested. The exercise consisted in pedaling a bicycle ergometer adjusted for an 8-pound pull for 1 mile at top speed. Under these conditions of rather strenuous exercise, no effect was discovered on either stereoscopic or vernier acuity.

In a final experiment in the series of Tufts College there was studied the performance of trained subjects on a complex task of 4 hours' duration. (573) The observer was instructed to operate continuously a knob regulating the rotation of speed of an inner dial, so as to align a pointer with an outer dial whose irregular speed of rotation was governed by a cam control. A number of accessory tasks were made to occur in a random sequence. He was required to watch a clock and indicate when each 10-minute period had elapsed; to signal when a model airplane reached certain points on a map; to indicate the presence of another aircraft which appeared on any of the four quadrants of the map. Five high school boys were used as subjects and they were given a week of preliminary training before the recorded trials were begun. This experiment was planned to test the hypothesis that observers would show signs of fatigue, as indicated in a decrement in efficiency of performance, when continuously engaged for relatively long periods of time in a task of psychological complexity. The results indicate no significant changes in performance were observed over the 4-hour period. From these results the authors conclude that observers may work continuously and effectively at a psychologically complex task of this type for several

hours without any significant change in the level of performance.

There was some clinical evidence which indicated that small degrees of aniseikonia, which were normally compensated for by the subject, might be so enhanced by fatigue that this compensatory control might be lost by the individual and the effects of false spatial localization resulting from the defect might become operative. A series of experiments were performed at the Dartmouth Eye Institute to study this problem. (189) The Dartmouth Tilting Board, described in the text, was employed. Subjects were fatigued by a continuation of normal activities over periods from 24 to 40 hours. The space eikonometer was also employed. In the first experiment, both normal and fatigue data were obtained from 11 subjects. With one exception the subjects showed no effects on spatial localization resulting from fatigue.

In a second report the tilting field was somewhat modified. (190) In this way the two parts of the field provided disparity clues for purposes of orientation. One part also provided a definite form clue. A total of 29 subjects were tested with this new device. Size lenses were worn in part of the experiment to produce aniseikonic effects. Under certain conditions there seemed to be a trend for some subjects to use stereoscopic and others to fall back on monocular clues such as form and perspective under the fatigue condition. It was also found with the space eikonometer that variations in stereoscopic response occur from day to day and under different conditions of the individual. All subjects when fatigued reported difficulty in making settings with the space eikonometer. This difficulty varied from a subjective uncertainty as to the exactness of their judgment to reports of variations in the appearance of the targets themselves. The time consumed in making the space eikonometer measurements was always longer when the subject was presumably in a fatigued condition. The interesting and paradoxical situation occurred, however, that in spite of this subjective difficulty and uncertainty, the actual measurements were made with the same degree of accuracy as under normal, unfatigued conditions.

A third report from the Dartmouth Eye Institute outlines experiments on 28 subjects with the modified tilting board. (191) Marked differences in binocular response are found among different individuals and in the same individual under different conditions, among which are those presumably resulting from fatigue. An outline of the problems to be investigated is included. The quantitative data for this report will be found elsewhere. (192)

A fourth report from the Dartmouth Eye Institute records further experiments on the effect of fatigue on spatial localization. (193) The apparatus was modified so that the effect of form clues upon the responses to specific types of binocular disparity relationships could be investigated. For example, if the effect of form upon localization based on horizontal disparity clues was to be studied, the stimulus situation (i.e., the fixed targets) should contain no clues that could be responded to on the basis of disparity relationships other than horizontal disparity differences. Hence a vertical tipping board was devised for these further experiments, as well as a modification of the space eikonometer. No new results of importance were reported. These experiments from the Dartmouth Eye Institute are summarized in a final summary report. (194) So far as effects of fatigue upon spatial localization are concerned, the general conclusion is that when subjects have gone without sleep for at least 24 hours, marked variations, in respect to accuracy and consistency with which they respond to introduced differences in binocular disparities, occur for some subjects. These variations however, cannot be considered to be consistently or characteristically different from the usual day to day variations. From this the investigators conclude that the experiments yielded equivocal results with respect to the effect of fatigue on stereoscopic spatial localization. Certainly these experiments failed to demonstrate any consistent fatigue effect.

As a result of these experiments at Tufts College and the Dartmouth Eye Institute, the Fire Control Division of NDRC made a report to the Services. (29) None of the tests at either institution showed important degrading effects. Indeed the results indicate that the ocular functions employed both in stereoscopic ranging or tracking are extremely resistant to fatigue effects. This is certainly true for relatively short periods of operation following either loss of sleep or loss of sleep plus long periods of alertness or exercise. However, it has been demonstrated that the power of persistent attention over a long period may be affected by such a procedure. This conclusion is true, although the subjects may show significant clinical signs of general fatigue as indicated by marked personality changes. Hence it was concluded that no special precautions against fatigue

are necessary in the case of tracking or stereoscopic ranging personnel.

9.2.1 Some Remarks on Motivation

One by-product of the experiments on fatigue, noted above, is that increased motivation may temporarily reduce the decrement of performance produced by the fatigue condition. There are several other experiments reported by the Tufts College group which bear upon this topic. The first study has to do with the effects of knowledge of results during training in ranging on a moving target. (563) Six observers were trained on stereoscopic range finding on the Tufts Trainer, in which the operator is required to adjust the distance of a moving target so that it will be at the same distance as a reticle mark. Knowledge of results was given the observers by sounding a buzzer whenever the distance between target and reticle exceeded a predetermined maximum, which in some tests was 5 UOE and in others 2.5 UOE. For four observers, training consisted of three tests, each consisting of 30 90-second periods without knowledge, followed by one test with the buzzer signal sounding whenever the error exceeded 5 UOE and two tests with signal sounding whenever the error exceeded 2.5 UOE. For two subjects the buzzer signals, which indicated when the maximum allowable error was exceeded, were used throughout —for 0.5 UOE in the first test and for 2.5 UOE for the other 5 tests. It was found that four of the six subjects showed improvement, as measured by a decrease in the frequency of the buzzer signals from tests 5 to 6. The two subjects who did not show improvement in these terminal training series were the best subject (who was so good that further improvement should not be expected anyway) and the worst subject (whose terminal performance was 24 times as bad as that of the best operator and who therefore was undoubtedly a person not qualified for this sort of training in any case).

The permanence of the improvement induced by knowledge of results was investigated by giving the subjects two additional tests without use of the knowledge of results signals. The results show that the improvement induced by knowledge of results began to wear off almost immediately. From these results the investigators conclude that the performance in tasks such as range finding is improved by arranging the situation so that the observer knows when he is doing well and when he is doing badly. Also, if improvement is to be maintained, knowledge of results must be maintained as well. In the range finding operation, knowledge of results seems to act as an incentive to action, or as a motivating device, rather than as a cue to learning. It may be pointed out that one of the great advantages of the M6 Trainer over the M2 instrument is the fact that the former has incorporated a recording device and an integrator so that the operator under training may have immediate knowledge of his results after each run. These facts are also incorporated in the Training Manual (68, 70, 71).

Tufts College investigated another motivational device which consisted of bell pacing in the range finder operation. (559) The Tufts Trainer was again used. Two groups of subjects were used: The first consisted of five high school students who made six 5-minute runs per session for six sessions. For this group, a bell sounded every 10 seconds and they signalled contact as soon afterwards as they were sure they had true range. Group II consisted of six college students who made 30 runs of 90 seconds duration at each of 15 sessions. For this second group, no bell was used in some sessions, whereas in others the time interval between bells was either 10, 5, or 3.3 seconds. Every subject in both groups was instructed to maintain true range at all times regardless of other variations in procedure. A graphic record of results was obtained for all runs. The results were somewhat equivocal. There was no reliable difference between the mean errors under the two conditions, but for all subjects consistency was greater (i.e., the standard deviation was smaller) for settings at time of contact than for settings made at time of onset of the bell. However, marked individual differences were discovered. Thus one subject always reduced his constant error at bell contact while another subject did so only twice in the entire experiment. It was hoped that the presence of the bell might act as a motivating agent to induce the operator to improve or correct his setting. This seemed effective in the case of some subjects but not in the case of others. Also it was found that the spacing of the bell signals had no significant effect within the limits tested. Hence the investigators conclude that for ranging which is performed continuously performance is significantly improved in some subjects (and not at all degraded for the others) at intermittent times of heightened

attention and that one means of obtaining this is by some bell pacing device at which times the operator is instructed to make a special effort to correct his setting. The frequency of the periods of such heightened attention seems to be unimportant for frequencies from 1 to 3 times per 10-second interval.

9.3 EFFECT OF LAYOFF

In a number of laboratory experiments, interruption of testing after subjects had been highly trained made it possible to study the effects of a layoff of variable length upon range finding performance. It had been reported by Service personnel that there is a decrease in ranging efficiency following even so short a period as a week-end layoff. This is consistent with the experience of industry where it is found that the worker's efficiency is relatively low at the beginning of a work week and increases toward the middle of the week. However, with the transportation of Service personnel to remote battle areas, it is conceived that considerable periods of time may be expected during which the personnel may be unable to practice operation of the stereo range finder instruments.

At the Tufts College laboratory, six subjects were given seven test sessions during which they were required to range continuously on a moving target on the Tufts Trainer. (571) Each test session consisted of 30 90-second runs with a 30-second rest period between runs. The experimental conditions during each test session were not constant inasmuch as this was a by-product of an experiment aimed at testing another variable. Some of these subjects were given knowledge of results training and a motivating bell signal and others merely kept continuous contact. During this training period, the learning curve leveled off to an approximately constant value in terms of consistency of performance. After the seventh training period a 2-week period of no work was introduced and the subjects were brought back to the apparatus after this time of layoff. The subjects were unaware of the fact that a special experiment was done on the effects of disuse. This is important because numerous psychological experiments have shown that the subject will often set or prepare himself for the time span between test and retest if he knows what this interval will be. Five of the six subjects showed a statistically significant decrement in ranging consistency resulting from the 2-weeks period of no practice. A special explanation seems warranted to account for this single subject whose results do not show a decrement. The Tufts College investigators conclude from these experiments that practice periods in ranging should occur at less than 2-week intervals and that morale may also be affected and motivation lowered by the period of disuse.

Another experiment on the effects of disuse on ranging efficiency was performed at the Howe Laboratory of Ophthalmology with very much longer periods of disuse, of approximately 3 to 6 months after the original training. (311) A simplified multicourse trainer was employed. Three types of target were used: (1) black side lines, (2) a black silhouette of a diving plane, and (3) a projected colored motion picture of a diving plane. Both fixed and dynamic targets were used. The dynamic targets produced the rate of disparateness which would be produced in a Mark 42 Range Finder by a plane diving at 300 knots from 25,000 to 5,000 feet with either 0, 100, or 250 knots regeneration supplied. Five stationary settings of each type were recorded for each observer; while three front-to-back, make-and-break, and three continuous tracking runs were recorded for each type of target.

These subjects had had a very considerable amount of training on other ranging apparatus before the layoff. They had not previously operated the simplified stereoscopic trainer used in the final tests. But the experimenters are of the opinion that the tasks before training are comparable to those performed after lack of practice. Four of the five subjects showed a decrement due to disuse ranging from 7 to 41 per cent of the previously trained performance level. One of the subjects, however, showed a decided gain of over 30 per cent following the period of no practice. This subject was also one of the experimenters and it may be assumed that his motivation remained extremely high for the retest.

On the other hand, a comparison of the results of these six previously highly trained observers with those of 21 untrained observers indicates that a period of disuse of from 3 to 6 months is by no means the basis for the loss of all of the effects of previous training. Even after the layoff, the previously trained subjects have an error very considerably less than those who were beginning training. Hence these results show a startlingly great superiority of the previously trained observers in spite of the decrement of their efficiency due to disuse over a long period. Even

for the fixed targets, which are relatively easy, they show a superiority of more than 90 per cent. For the more difficult moving target situation, the superiority of the previously trained observers is very much greater—being 139 and 161 per cent for the different types of target, and 263 per cent for the most difficult situation of the projected motion picture of the diving target. It should again be noted that these six observers were very highly trained at the start of the period of disuse.

A small amount of data is available from Fort Monroe on this problem of disuse in the actual field situation. These are results from the Height Finder School and were contained in an unpublished memorandum. These observers were not highly trained. The results are given in UOE error for both fixed and aerial targets, using the M1 Height Finder, the M2 Trainer in its dynamic form and the Eastman Trainer. Performance at the end of the previous week and of Monday and Tuesday performances are compared. In all six cases for the three instruments and for fixed and aerial targets, these average differences are small, and in no case are they statistically significant. The variations are of a chance character and show no constant trend for the different experimental variables. Hence it may be concluded that a week-end layoff during training causes no serious decrement in ranging efficiency.

There are no data regarding the rapidity of relearning in those cases where a decrement due to disuse is evident. The entire pattern of results, however, is totally in conformity with well-known psychological principles of learning and forgetting and, following these, it can be safely predicted that it would take a shorter period of relearning for the operators to reach their previous level of efficiency than was required to produce a similar increment of improvement in the initial learning periods.

The experimental data reported in this section on the effects of disuse is somewhat meager. The following conclusions to disuse on stereoscopic ranging efficiency seem justified, however, especially as they fit into well-known psychological observations for somewhat similar operations. (1) A period of disuse of 2 weeks or more leads to a decrement of performance which is statistically significant for many observers. (2) A period of disuse for a single day does not demonstrate such a decrement. (3) The amount of decrement is affected by such factors as (a) the length of the period of disuse; (b) the difficulty of the ranging problem; (c) the level of training before the layoff and (d) the motivation of the observer. (4) The longer the period of disuse and the more difficult the problem the greater the decrement. (5) The higher the level of training before the period of disuse and the greater the motivation of the observer, the smaller will be the decrement. (6) If the operator has been very highly trained before the period of disuse, he shows a very great superiority over an untrained subject even after a layoff of from 3 to 6 months, indicating that much of the efficiency due to the previous training has been retained in spite of the long period of disuse.

It can be recommended: (1) That all stereoscopic range finder operators be as highly trained as the situation permits in the initial training period. (2) That this training be continued as frequently and as intensively as the situation permits. (3) That, if an observer has not made stereoscopic range operations over a period of a week, he be given an intensive period of relearning at the first possible opportunity and he be given practice in observing regularly thereafter as the situation may permit.

9.4 THE EFFECT OF LOUD SOUNDS ON STEREOSCOPIC RANGING AND TRACKING

It may be believed that loud sounds such as one might encounter in battle may have an effect on ranging and tracking efficiency. An opportunity to test this hypothesis was offered through the cooperation of Section C-5, NDRC, which made available the apparatus and records developed under contract with Stevens Institute. This includes a record player, amplifier, and specially designed head phones. There are separate volume controls, one operated by the observer and the other by the experimenter. The sounds used are designated as BJ cuts numbers 1 to 7. A commercial record (Spe-D-Q7921A, Warfare No. 15) of air raid sounds, including planes and bombs, was also used. The volume was never less than 100 db in the experiments and went as high as 128-130 db.

One experiment was performed at Tufts College. (548) The sounds were introduced as a part of a fatigue test in a tracking experiment. The subjects viewed a target in a Navy Mark II Trainer which was displaced in azimuth by a motor-driven device. Five-minute samples were recorded at ½-hour periods throughout 4-hour tests of continuous track-

ing. The sounds were delivered to the subjects in three different patterns: (1) A 3-minute unannounced stimulation at the end of the 4-hour period; (2) Twelve sound periods of 2 minutes each during the 4-hour period; (3) Sounds introduced for 3 minutes at the middle and end of the 4-hour tracking period. In this last pattern, the sounds used were those reported as the most unpleasant for each observer.

When the sound was introduced at the end of the 4-hour test (pattern 1), no disruption of performance was produced. Indeed, there was improved tracking performance in the case of two observers and some deterioration in the case of a third. When the sounds were introduced periodically during the 4-hour period (pattern 2) there was found to be improved performance as measured by the work samples taken just preceding the introduction of the sound and those taken at ½-hour periods during the test. In the final test (pattern 3), the sound in all cases improved performance in spite of the fact that it was definitely more difficult to endure than it had been in the previous trials because the amplitude was increased from 120 to 130 db and the duration from 2 to 3 minutes.

Another experiment was carried on at Brown University. (133) Twelve observers were employed on the Brown Stereoscopic Trainer to determine the extent to which the presence of loud sounds affected an observer's efficiency in a task consisting of stereoscopic pursuit in range finding. Twelve successive runs were given the trained observers on each of 8 experimental days. On each day a total of 3 minutes exposure was given each man to the intense sound stimulation ranging from 100 to 128 db and the other runs were made without sound for purposes of comparison. The level of sound intensity was set by the subject himself before each day's experiment and represents the highest intensity which the individual, with some urging, was willing to endure.

The results indicate: (1) That in the experiment as a whole, there is no significant difference between scores for the observations with and without stimulation by intense sounds. (2) That in spite of marked individual differences in performance ability among the observers, there are no significant individual departures from the general finding that the presence of intense sounds was without effect on the stereoscopic scores. (3) That the results on the first experimental day, when the sounds might have caused more apprehension and surprise, are not significantly different from those on the other days. (4) That the constant error scores were no more changed than were the average deviation scores by the presence of loud sounds. These results were obtained even though the reports of the subjects indicated that the sounds produced effects on the sense of balance and of a tendency to pain and even nausea.

From these results it seems safe to say that loud sounds *per se* do not have an effect on these operators affecting efficiency of either stereoscopic ranging or tracking. However, it might be that through associative processes or the like, such sounds would cause difficulties in battle to certain emotionally unstable persons. This experiment should be of value as indicating that the problem of selection would not be in relation to sound, but rather to temperament.

These results are summarized in a Report to the Services issued by the Fire Control Section. (15) In this report it is indicated that, although muscular tension was produced, the introduction of the sounds were a relief from the monotony of the tasks, an aid in staying awake and hence acted, in some cases, as a motivational factor.

9.5 SEX DIFFERENCES

Experiments carried on in several research laboratories utilized both men and women subjects. Hence a comparison of sex differences was possible in some cases as a by-product of these experiments. According to some reports, the British were utilizing women for operating tracking and ranging mechanisms on range finders at relatively fixed antiaircraft installations. It was believed that the policy of both American Services of utilization of women by enlistment might lead to a similar employment of women's services in the future of this country.

At Tufts College the performance of a group of 56 men and of 32 women was measured on the Navy Stereo-Trainer Mark 2 and on the Tufts Stereotrainer. (567) Eight scores are available for each subject from each of two testing sessions. The men were all freshmen enrolled in the Naval ROTC Unit. All of these subjects had passed the rigorous visual acuity tests required of ROTC candidates, with at least 20/20 vision in each eye. The women were also students at Tufts College who volunteered to take these tests. While this group of women was certainly more highly selected than the average of the general popu-

lation, it seems probable that they were not as highly selected as the male subjects in this experiment, certainly with respect to ocular capacity and general health status.

In every case, the eight scores were obtained in a single session and repeated in a second session. The order of taking the tests in the session was randomized. The interval between the two test sessions varied from 2 days to 2 weeks. Each subject was tested twice with the two instruments. With both training instruments, a single test session included 20 settings with the target stationary and two 90-second runs with a moving target. The subjects were instructed to maintain contact continuously. All subjects were untrained at the beginning of the experiment. The results indicate that the performance between first and second tests was not significantly different either in the case of the men or women. In comparing the subjects of the two sexes, no differences in level of performance could be found by a statistical treatment of the results for either the initial performance in the first test, or on the second test after the small amount of practice.

In another experiment at Ohio State University both men and women were employed as subjects in connection with a study of the effects of the blurredness of the target in stereoscopic range finding. (338) An apparatus was employed by means of which the blurredness of the target outline and the degree of contrast between target and background could be varied independently. Nineteen men and eleven women acted as subjects. Their previous training varied from highly trained to relatively untrained. The results indicate that there is no sex difference which is statistically valid.

An incidental study of sex differences in aided tracking was made at Iowa State University. (317) There were no sex differences apparent, the men averaging 0.168 mil error and the women 0.171 mil error. This was true even though the men had had more tracking experience and had undergone more selection, on the basis of the tests themselves, than had the women.

At the Foxboro Company, an experiment was performed with direct tracking by hand wheel. (215, 216) The presentation was simplified as much as possible. The subjects consisted of ten men and ten women chosen at random from the personnel of the Foxboro Company. Without preliminary tests it was not possible to obtain completely matched groups of men and women, so it was decided to obtain a fair sampling of the population of the plant within the age limits of 18 to 35 years and also to match groups with respect to type of work and educational status. The preliminary results indicated a superiority of the men's group in this operation as judged by error scores and by variability measures. However, when the experiment was carried further, these differences were no longer significant after the ninth hour of practice. Hence the investigators conclude that, on this rather difficult problem requiring a high degree of application and dexterity, women learn more slowly than men, requiring a larger amount of practice to reach the level of men during all portions of the learning curve. With increased practice, however, the women can attain any level of accuracy reached by the men.

These reports are summarized in a Report to the Services issued by the Fire Control Division of NDRC. (28) It is here concluded that no important sex differences in ability to perform the tasks of either stereoscopic range finding or visual tracking have been demonstrated, except for the longer training period required for women as demonstrated in the Foxboro experiment reported above.

9.6 DRUGS AND OTHER FACTORS

Benzedrine Sulphate

Benzedrine sulphate has been suggested as a means of temporarily overcoming fatigue and the effects of loss of sleep. In order to test the efficiency of this drug, experiments were carried out at the Harvard Fatigue Laboratory. (273) Six subjects were used in the experiment with loss of sleep over a period of 23 to 27 hours. Readings were taken in the evening and again in the morning following the sleepless night. Their results were compared with those of a second experiment which was similar to the first except that 20 mg of benzedrine sulphate was ingested after the series of readings taken in the morning following the all-night vigil without rest. Twenty minutes after the ingestion of benzedrine sulphate another series of range estimates were taken. It was found that loss of sleep of a night's duration resulted in slight, but statistically insignificant, increases in the variability of range estimates. Five of the six subjects showed improved performance after the ingestion of benzedrine sulphate.

As a result of these experiments, the Fire Control

Division of NDRC made a recommendation to the Services as follows. (22) If benzedrine is given to overcome drowsiness following long periods of necessary wakefulness, it should be given with caution and, if at all possible, under the direction of a physician. The usefulness of this drug is seriously diminished because of (1) the latent time of the effect after ingestion, (2) the duration of the effect of a single dosage, (3) possible individual idiosyncrasies of the effect, (4) a possible deleterious result after the effect has worn off, and (5) possible deleterious effects of too frequent or too continued dosage.

Metrazol

From an entirely different point of view, an experiment was carried on at the Harvard Fatigue Laboratory to determine if it might be possible to find a drug which would improve stereoscopic and/or vernier acuity. (274) After conference with physiologists, it was decided to try the effects of metrazol (a synthetic organic tetrazol compound) because it was advised that this drug was the best available cerebral and respiratory stimulant and hence was most suited for this purpose. Fifty-two experiments were carried out on the effects of metrazol on visual acuity. Forty of these experiments were made on stereoscopic acuity and the remaining 12 on vernier acuity. Metrazol was administered in 1.5 to 7.5 grain dosages. It was found that the ingestion of this drug had no significant effect on the variability of stereo or vernier range estimates. The increase or decrease in the time necessary to make 40 readings was calculated for stereo acuity. In 100 out of 132 comparisons of time in making the judgments, there was an increase in the speed of range settings after the ingestion of metrazol without an apparent decrease in the precision of these settings. Only 5 cases showed a decrease in speed after metrazol ingestion. The average correlation between the mean variation and the time for making judgments was $+0.50$. This indicates that metrazol, a respiratory and cerebral stimulant, gave rise to both an increase in speed and precision of range estimates. No direct relation was found between the amount of metrazol administered and the amount of increase in speed of judging observer. The results for vernier acuity showed no such effects after ingestion of metrazol. The critical ratios for differences between vernier readings before and after metrazol were mostly not significant so far as variability of readings was concerned. In spite of the slight advantage in speed of making stereo judgments which were demonstrated by this study, it was not deemed that sufficient improvement in stereo ranging had been demonstrated and hence the Fire Control Division of NDRC made no recommendation to the Services advising the use of this drug.

Startle

Still another experiment carried on at the Harvard Fatigue Laboratory had to do with the effects of startle on pupil size and its effects on stereo and vernier acuity. (276) It is well known that one of the effects of sudden startle, such as would be produced by the unexpected firing of a pistol just behind the subject, is a dilation of the size of the pupil of the eye. Photographs of the pupil taken before and after the startle demonstrated an increase in pupil size of an average of 0.3 mm immediately after stimulation. The pupil size gradually returns to normal during the course of 1 minute. Although this pattern was exhibited almost without exception by all 36 subjects, it was found that emotionally unstable subjects showed a relatively greater increase in the size of the pupil. It appeared, however, that this amount of variation in pupil size had no significance for range finding, since there was no change in variability for either stereoscopic or vernier acuity.

Variations in Blood Sugar

At the Harvard Fatigue Laboratory a study was made on the effects of variations in blood sugar on stereoscopic and vernier acuity. (277) Sixteen subjects came to the laboratory in a basal condition and observations were made on stereo acuity. They were then given dextrose to observe any possible effects due to an increase in the blood sugar level. Another series of experiments were carried out in which range estimates for both stereo and vernier acuity were made while the subject was in a basal state and again at standard intervals after the injection of insulin in order to reduce the blood sugar level below normal. At the conclusion of each insulin test the subject ingested dextrose, after which observations were repeated on stereo and vernier acuity. These latter experiments were twice repeated. In the first series, a moderate dose of insulin was given and, in the second series, a fairly large dose was given to lower the blood sugar to approximately 50 mg per cent. It was found that no significant differences were observed in the stereo range settings made under

basal as contrasted with non-basal conditions. When the level of the blood sugar was lowered by insulin, however, there was an increase in variability and, in some cases, even a departure from true range. Vernier acuity appeared to be more easily influenced by the lowered blood sugar than stereo acuity. This was especially true with the larger doses of insulin. The results indicate, therefore, that vernier acuity is more easily varied than stereo acuity by the stress imposed by lowered blood sugar. Inasmuch as no effect of lowered blood sugar was demonstrated for a degree likely to be met in actual operations, no specific recommendation was made by the Fire Control Division of NDRC.

Low Oxygen and Low Illumination

The effects of low oxygen and low illumination on stereo and vernier acuity were reported by the Harvard Fatigue Laboratory. (278) The effect of reduced percentages of oxygen in the inspired air was studied in 22 experiments using six subjects. A control experiment was made with normal air, another series with 12 per cent oxygen (corresponding to an altitude of 10,000 feet), and a third with 10 per cent oxygen (corresponding to an altitude of 19,000 feet). In the final series of tests the illumination was reduced while inhaling 10 per cent concentrations of oxygen. Observations were made for both stereo and vernier acuity. Under conditions of normal illumination, the 12 per cent oxygen concentrations showed practically no effects. When the oxygen was reduced to 10 per cent, however, most of the subjects showed an increased variability in vernier acuity, with only slight effects on stereo acuity. Under the low illumination of 0.1 ft-c with 10 per cent oxygen, these effects were much more striking, especially the greater variability of vernier compared with stereo acuity. Under the conditions of these experiments vernier acuity appears to be more susceptible to the impairing effects of oxygen deprivation than stereo acuity.

Posture

It was believed that changes in posture might give rise to reduced visual performance inasmuch as this had already been demonstrated in the case of light sensitivity. It had been found that reduction in light sensitivity may be produced by the altered blood flow or altered blood pressure associated with postural changes and may be correlated with a reduction in the amount of blood available for the nerve cells and the visual area of the brain. The basis of this kind of visual impairment may be the decreased oxidation occasioned by the lowered amount, or pressure, of the blood in the brain. The two Services employ different postures for the range finder operator—standing for the Army and sitting for the Navy. A study of stereoscopic range measurements made under these different postural positions was performed at the Harvard Fatigue Laboratory. (266, 268) Experiments were carried on under a variety of conditions: (1) experiments with a tilt table; (2) tilt table experiments with the blood pressure lowered by administration of nitroglycerin; (3) half hour standing periods; (4) ingestion of nitroglycerin while sitting and (5) prolonged (3-hour) periods of standing.

A total of 84 experiments in the study of the effect of posture on stereo range estimates were made. The results indicated consistently that the variability of stereo range readings did not alter with (a) change in posture, (b) with the ingestion of nitroglycerin, or (c) with both changes in posture and the ingestion of nitroglycerin simultaneously. Only one subject showed an increased variability after the tilt table or nitroglycerin and he usually gave a poor response to the tilt table. Thirty-one experiments were carried out during periods of 3-hour prolonged standing. Three of the five subjects became more variable and showed a progressive departure from true range as the experiment progressed. The subject who showed the greatest variability and the largest departure from true range also gave the poorest responses to the tilt table. However, the observed changes in variability were, on the average, all less than 1 unit of error. Hence the general conclusion from these postural studies is that stereo acuity remains relatively unaffected, i.e., the changes in precision were less than 12 seconds of arc, regardless of the fairly severe physiological effects resulting from the altered posture imposed by these experiments.

9.7 GENERAL CONCLUSION

Indeed, the general conclusion to be drawn from the experiments outlined in this chapter of the present report is that stereoscopic range finding is curiously, and gratifyingly, resistant to psycho-physiological changes in the operator. This is true for fatigue, loss of sleep, drugs such as metrazol, oxygen deprivation, and postural changes. Hyperventilation produced a damaging effect of short duration and

benzedrine produced a salutary effect in overcoming fatigue. Mention has been made above of the recommendation of the Fire Control Division of NDRC to the Services in regard to the use of benzedrine. In regard to hyperventilation, the Fire Control Division recommended (22) that height and range finder personnel should be stationed close enough to their instruments so that, in the case of an alert, it will not be necessary for them to run a distance great enough to produce deep and rapid breathing. Although the effects of hyperventilation, induced in this way, are of short duration, they might occur at a very critical time in the case of a sudden alert.

It is comforting indeed to find that the results of all of the other carefully performed experiments gave negative results, and hence the practical effects of these factors may be ignored in the field and during combat.

Chapter 10

RELATIVE POSITION OF RETICLE AND TARGET AND IMPORTANCE OF TRACKING

10.1 STUDIES ON RELATION OF RETICLE TO TARGET

A NUMBER OF experiments have been performed in several laboratories which were concerned with the relative position of target and reticle in stereoscopic range finding. Such an experiment was carried on at Tufts College. (556) Records were obtained from six trained observers on both the Tufts Stereoscopic Trainer and the Mark II Stereoscopic Training Instrument. The target was placed at 9 seconds of arc above or below the limits of the fiducial mark of the reticle. The results indicate that, for five of the six subjects, there were significant differences in the precision of ranging and that the results of the sixth subject approached statistical significance. The difference between the means of error from readings in one position to means of error in the second position varied from 4.4 seconds to 63.3 seconds of parallactic angle at the observer's eye. All of these observers had previously been trained, too, with the target under the reticle. Nevertheless the results show that for most subjects in this experiment, the target position above the reticle seemed to produce smaller constant errors. Three untrained subjects also took part in this experiment. Constant differences of similar magnitude were found in the cases of two of them but not for the third.

Also at Tufts College the experiments were repeated using the Mark II Trainer. The results indicate that significant differences were obtained between the means for seven out of ten series of observations, but the direction of error does not always correspond for the two instruments. For three observers there is the same tilt in the two instruments; while for three other observers there is the opposite tilt. The differences in average error for the two target positions range from 3 to 87 seconds for different subjects. It should also be noted that those subjects who showed a relatively large error on one instrument showed it on the other as well.

From these results the investigators conclude that the target position effect discovered in the Tufts Trainer is also present with some subjects in the Navy Trainer. Those subjects whose differences between means of target-above trials and target-below trials were large showed the same kind of difference in the Navy Trainer. These results mean that on both the Tufts Trainer and in the Navy Trainer the criterion of contact is influenced by the target position in the vertical meridian.

In another experiment at the Howe Laboratory of Ophthalmology, six trained observers were employed and the target was systematically shifted above or below the fiducial mark of the reticle in steps of 6 degrees, 4 degrees and 2 degrees. (306) The observer was allowed to bracket at will in making his range setting. The results indicate that each observer exhibited a steady progression in the average error as the target rises from 6 degrees below the fiducial mark to 6 degrees above; but both the magnitude and direction of the progression vary markedly from observer to observer. It will also be noted that the precision of the settings, as measured by the mean absolute deviation, is always best at the central position of zero separation of target and fiducial line in the vertical meridian. The experimenters report that there was great constancy of ranging for each observer for observations made over a period of 6 months.

In another experiment at the Howe Laboratory, also employing the Mark II Trainer, results were obtained from four subjects with the target placed at 0.6 degrees, 1 degree, 2 degrees, 3 degrees and 4 degrees above the reticle. (307) Observations were also obtained with similar separations in free space. The results indicate, in general, that the trend observable in the stereoscopic training instrument is essentially absent in free space. However, with the Trainer there is in every case a consistent error trend which increases as the separation between reticle and target is increased and, in the case of five subjects, becomes very large with a separation as great as 6 degrees.

An experiment was made at the Harvard Fatigue Laboratory on lateral displacement of target and fiducial reticle line. (264) The angle of displacement extended to 5 degrees on either side of the extreme reticle posts or 10 degrees on either side of the central fiducial diamond. Determinations were made with the binocular acuity apparatus developed by the

Fatigue Laboratory. Nine subjects each made repeated determinations at 14 different separations—7 on each side of the fiducial marks.

The results indicate that there are no effects of any considerable magnitude for any of the nine subjects when the target remains within the extreme lateral limits of the reticle. However, the loss of acuity is very great indeed when the target is placed outside these limits and at the extreme separation may become as much as 440 seconds of parallactic angle. Most observers show a decrease in range estimates at the extreme position on either side of the reticle but individual differences in the direction of the error were noted. At the extremes, however, increase in both average error and in variability of ranging were noted for all observers.

No extended systematic experiments were performed on this topic at the Princeton Laboratory, Fort Monroe, but there were a number of observations some of which are of particular importance, being made on the actual Army Stereoscopic Height Finder M1.[a] In one series of observations, ranges were taken with the target directly beside the fiducial mark or with the target below the central reticle post. The results for three of four subjects show a statistically significant difference in the range when the target is just beside or below the central reticle post. In the case of all of the four highly trained observers there is an increase in error for the below position—for one subject as great as 60 seconds of arc. Also, for every subject, this error is still further increased under conditions of haze. It seems safe to conclude that one will obtain a longer range when the target is under than when the target is beside the fiducial line.

There is also a small amount of data available from the Princeton Laboratory for readings taken on the Eastman Trainer. The target was placed either 1 or 2 lengths of the fiducial post directly above or directly below it. (372) The results indicate that there is a tendency to range shorter with the target above the reticle than with the target below and that this effect increases with increase in target-reticle separation.

Some results from Brown University throw additional light on the problem of target and reticle separation, although the experiment was devised for a somewhat different purpose. (164) This study was concerned with a comparison of two simple types of reticle pattern and with an analysis of the way in which precision of stereoscopic setting is influenced by nearness of the target to a reference fiducial line. One group of reticles consisted of a single vertical line with the target set at different distances to the right. A second group of reticles consisted of different sizes of break in a single vertical line. The target was entered in the middle of such breaks. Fixed targets were used throughout. Hence in the first group, these investigators studied lateral separation of target and reticle and, in the second case, vertical separation.

Both situations give the same results. As the fiducial line is moved farther and farther from the target, the precision of stereoscopic setting decreases. At comparable line-to-target distances, the reticles of the break-in-line type gave better precisions than the reticle of a single line placed laterally to the target. The average deviation for five experienced observers for 5 degrees separation of target and reticle was nearly 62 seconds of arc; in the break-in-line type where the widest break was slightly more than 3.5 degrees the average deviation was slightly over 30 seconds of arc. The results indicate that, in designing reticles, emphasis should be placed on the possibility of positioning the target in a break in the fiducial line or of presenting reticle patterns which give an opportunity for the target to be as near fiducial lines as possible.

Much of this material has been gathered together in a Report to the Services issued by the Fire Control Division of NDRC. (8) There is no conclusive evidence regarding the cause of these effects on ranging of separation of reticle and target. That they are due to viewing through an optical system would seem likely from the comparison of Trainer and free space results of the Howe Laboratory. The suggestion has been made that these errors may be due to such eye conditions as cyclophoria, which would result in various tiltings of the field for different observers. The individual differences in degree and even direction of the errors noted in all of the results outlined above from the different laboratories would tend to support this view. Whatever their cause, these results indicate the existence of errors of very considerable magnitude when ranging is done with target position in the field beyond the limits of the reticle pattern, either vertically or horizontally. The results are of special interest to the range finder operator since

[a]These results are contained in a memorandum from the Princeton Laboratory dated May 6-8, 1942.

they point to the importance of accurate tracking of the target in order to maintain the position of the target as near the center of the reticle as possible.

There is also a report on tracking errors from the Princeton Laboratory at Fort Monroe. (372) This contains empirical results which come from an experiment at Fort Monroe in October 1941 and also a theoretical discussion of the effects of such errors on the accuracy of stereoscopic range finding. Angular tracking errors can cause height errors in the case of the M1 Height Finder in two ways: (1) an elevation error will cause the dial reading to differ from true height, even though the target is correctly set on the reticles, and (2) irregular tracking will cause the target to jump about in the field of view of the observer, thus making observing more difficult and possibly less precise. This first type of error is not present when the M1 instrument is used as a range finder. Working with the M2 Trainer the experiment was performed with 27 student observers, with and without tracking errors. The performance of the class as a whole was significantly better, at the 5 per cent level, without tracking errors. How much better depended very much on the particular observer. The more accomplished observers generally showed the least difference under the two conditions of tracking. One of the quantitative results of the Fort Monroe test is that the standard error of elevation tracking is generally of the order of one mil. Hence the standard deviation of these errors would be less than 0.6 UOE for an altitude of 3,000 yards or greater.

10.2 EXPERIMENTS ON HANDWHEEL TRACKING

In order to study tracking accuracies and also to provide an instrument to be used as a trainer for the tracking on the M7 Director, Tufts College developed an instrument which was called the Tufts Director Tracking Trainer. (575, 577) This instrument is described and pictured in the second of these reports. In external appearance, general dimensions, position of handwheels, eyepieces, etc., it is similar to the actual director. The telescopes, however, instead of being pointed toward external space, are trained upon an internal target. This target is made to move along a spherical course upon a fixed center point and can be followed in both azimuth and elevation by the tracking telescopes which can be rotated independently about the same center point. Any desired course can be simulated for the target by introduction of proper cams. Hence tracking practice of a very realistic sort may be obtained without actual flying missions and, immediately after every run, an integrated error score may be given to the operator. Preliminary results indicated that the instrument was valuable in the early stages of tracking training. However, because of the size of the instrument and its expense, it was not adopted by the Army.

Because of these facts and other considerations, a detailed and systematic program of experiments for handwheel tracking were performed by the Foxboro Company. This work was undertaken because it was found that there was no information available on the limitations of performance of a human operator tracking with a handwheel. Furthermore, the matter of smooth tracking in fire control problems was increasing in importance to the point of being a major factor in accuracy in gun laying. Hence these studies have a very much wider interest and application than the mere centering of the target image on the reticle of the range finder. They are of the utmost importance for director operators and for the following of a target by automatic weapons.

10.2.1 The Human Operator

Conditions of Experiment

The first report of the Foxboro Company covers the broad phases of the problem of the human operator and the tracking problem. (33) A description of the apparatus developed to study these problems is included. Various courses could be introduced by the mere substitution of cams. For most of the experiments the presentation was simple pointer matching. The subject, by operating a handwheel, had to correct the movement of one pointer, actuated by the cam device, so that it stayed matched with a second stationary pointer. In some experiments, to determine if the principles developed for pointer matching were universal for other presentations of data, the subjects were required to match pips on an oscilloscope, a very different sort of presentation. The subjects were chosen at random from the personnel of the Foxboro Company, and represented a fair sampling of the plant population within the age limits of 18 to 35 years. Hence it was believed that their subjects were not different from those actually operating such devices in the Services. The apparatus

enabled the experimenters, for every run, to obtain an integrated error score and also a graphic record of errors throughout the run.

Learning Curve

The first experiment was designed to study the learning curve of all operators and to bring each to his state of greatest efficiency. In every case the complexity of the learning is shown by the high error scores at the beginning of the experiment, by the irregular drops, the plateaus, and the relatively large number of runs necessary to reach the physiological limit of tracking performance. For example, for one group of observers the mean error score for the first ten runs is 192 while for the 51st to 60th runs this drops to 92. For another group of 10 observers the mean error score for the first 10 runs is 187, dropping to 85 for the 51st to 60th runs. In many subjects there is evidence that learning was not complete by the 60th run.

It is often said that measures of performance for different individuals approach each other with practice in simple tasks and tend to diverge in more complicated ones. While the absolute error scores in the present experiment decreased with practice, the results show that the ratio of poorest to best operators does not show any such decrease. Hence the investigators conclude that there are factors making for more efficient performance which result in lowered absolute error scores and factors making for individual differences in tracking ability which remain even after considerable practice. For the last ten runs, for example, the mean error scores for individuals varied from 144 to 39. The range ratios show that the poorest subjects make error scores nearly 400 per cent as great as the best. The five poorest operators were no more accurate after 60 runs than the five best were after 10 runs, the former having an average error score of 127 at the end of this training as compared with 132 for the latter during the first 10 runs.

The graphic records of error in pointer displacement are given for good, average, and poor operators at the beginning, middle, and end of this training period. In the beginning the tracking of all operators, and of poorer operators even after many runs, showed swings of large amplitude and low frequency; the operator turned too far to one side and then overshot in bringing the pointer back to zero. More turns of the handwheel were made than were necessary. As operators improve the swings are reduced in amplitude, the low frequency drift tends to drop out, and the line of true target position is approached more frequently. For example, the displacement curves for one of the poorest operators show she was practically never on or near the zero line; those of the better operators show frequent contacts and small departures from the zero line. On the whole, operators tend to lag behind the pointer in that their corrections of pointer displacements approach the zero line without crossing it, showing that they do not correct by deviating as much to the opposite side as they did on the original. The result is that the average deviation, taken with regard to sign, is not zero but a plus or minus quantity depending upon which side the lag occurred.

The gross behavior of operators learning to track parallels the picture gained from the tracking plots. The beginner or the poor operator works harder, is more tense and actually expends more energy than the skilled tracker. The good tracker holds the knob of the handwheel lightly in his fingers and his arm and wrist are free almost to relaxation. One gets the impression that he is following rather than pushing the pointer. But good trackers are actually not taking it easy; they are attentively alert and thereby do the job with the minimum expenditure of energy. At the end of the training the best operators were at accuracy levels of tracking better than 1 mil while the poorest were doing not better than 3.7 mils after the 60 runs of practice.

Effect of Handwheel Position

This preliminary experiment was designed also to test one other factor — namely, the position of the handwheel as it might affect the accuracy of tracking a moving pointer against a stationary standard. Two positions of the handwheel were selected for study; a vertical position in which the handwheel was turning in the plane parallel to the body of the operator and at right angles to the floor, and a horizontal one in which the plane of motion was at right angles to the body of the operator. From the beginning of the experiment the operators were divided into two groups. One group started with the handwheel in the vertical position and, after 30 runs, switched to the handwheel in the horizontal position. The second group followed the same experimental pattern but reversed the order for the two handwheel positions. It was found that the differences between

averages of runs of 10 between the two groups are not statistically reliable and hence it may be concluded that there is no permanent advantage in either position, even though the vertical position affords hand movements which more nearly correspond to desired target motion. Comparison of the average of the last five runs with first position and first five runs of second position shows that there is a significant increase in error score when vertical is changed to horizontal and a slight, but statistically insignificant drop when horizontal is changed to vertical. In both groups the downward trend of the learning curve was stopped, showing that any change in handwheel position opposed to previously formed habits is at least temporarily disruptive. However, after 10 additional runs all operators adjusted to the new position and learning proceeded in orderly fashion.

An analysis of individual differences in tracking accuracy was made of the 20 subjects who worked as operators in this initial experiment. Individual differences appeared from the beginning and were maintained to the end of the 60th run. The ratio of poorest to best operator was 3.09 for the first 10 runs and 3.69 for the sixth set of 10 runs. For the group as a whole the ratios tend to increase rather than to decrease, the better operators becoming relatively worse with practice. Also operators tend to keep their relative positions in accuracy of tracking. If one divides the 20 operators into quartiles of five each, one finds on comparative standing in the last group of 10 runs that : (1) four of the five operators in the highest quartile remain in this quartile while the fifth moves to the second quartile; (2) four of the five operators in the lowest quartile remain in that quartile while the fifth moves up to the third quartile. These results have practical consequences. It appears that the best and poorest operators hardly change position, whereas the average (those in the middle quartile) change most. Furthermore the average operators do not, as a rule, jump to best or poorest positions after additional training but tend rather to move into continuous central quartiles. For the whole group, correlation between rank order after 10 runs and after 60 runs is 0.68; while that between the third and sixth group of runs is 0.85. This indicates that, in a sense, good trackers are born and not made. Hence, if it is desired to select a group of men who will become good trackers, some sort of selection procedure should be employed. For example, the upper 50 per cent of operators in this group after the 30th run would have given a range ratio from best to worst of 2.23; by choosing operators from the upper quartile only, the range ratio drops to 1.56 instead of the 3.69 value for the entire group. It is possible that some of the poorer operators could be improved with special training but this will not occur beyond the limits indicated by mere practice alone.

The question of sex differences in these experiments has been discussed elsewhere in this report.

These experiments were continued and the results are to be found in a second report from the Foxboro Company. (34) The conditions of presentation of data remained the same as those in the first experiment already described. A total of 12 men and women acted as operators. These were unselected and untrained at the beginning of the experiment. A third oblique position of the handwheel was introduced as well as the vertical and horizontal positions already studied. The same pattern of learning curve, variability, individual differences, and sex differences was found for this group as for those previously tested. It was found that shift from vertical to oblique position of handwheel slightly interrupted the learning curve but had no greater effect than a subsequent shift from oblique to the horizontal position. Hence these results indicate that considerable latitude is possible in handwheel position in actual field operation. In certain pieces of field apparatus all three handwheel positions—vertical, horizontal and oblique will be found.

Effect of Fatigue

In another experiment found in this report by the Foxboro Company an attempt was made to discover possible effects of prolonged work on tracking performance. Fatigue runs were made with 12 operators under two sets of conditions. One group of subjects rested during change of error records after each trial, thus breaking runs with rest periods of from 30 to 45 seconds; the other group made continuous runs with no break between trials whatsoever until a considerable number of runs had been made. Each of the three positions of the handwheel was used under both conditions of work. A total of 30 to 40 runs were made in a single second requiring continuous operations during a period of several hours. The results fail to show any work decrement because of this continuous tracking to the extent expected from

continuous work of this sort. In one case only is there an increase in error score as the work progresses, which is the classical curve of work decrement. For five operators there is a more or less gradual rise in error followed by a drop so that the tracking at the end of the period is as good or even better than at the beginning. For three subjects there was fairly steady performance with very little or no loss in efficiency as evidence of fatigue or work decrement. For the remaining three operators there was progressive increase in efficiency shown by drops in the error curve throughout the work period. Hence it appears that even when tracking is prolonged for as long as 3 hours with little or no pause between runs, no breaking point or gradual loss in efficiency occurs, as measured by average errors. However, 8 of the 12 operators had greater variability of results under fatigue conditions than was found for them in normal runs. Under the conditions of this experiment it seems that fatigue does appear in increased variability of tracking accuracy although average accuracy is unimpaired.

With an eye toward selection of persons who would make good trackers with training, the Foxboro investigators chose a type of reaction time experiment which might be regarded as a spot or work sample tracking response, involving discrimination and choice as well as speed of reaction. A pointer could be made to move either to the right or left in random order from a position directly above a stationary marker. The subject was given the task of responding to the moving pointer by pressing a lever similar to a telegrapher's lever held between thumb and index finger. The subject was required to press the lever in a direction opposite to the motion of the pointer. The average reaction time for 28 subjects for such directional response is 406 milliseconds (ms). This is considerably above simple reaction times to light—178 ms; to sound—154 ms; and either light-or-sound—200 ms, as obtained from the same apparatus. Highly significant individual differences were present in the reaction times of these subjects. A positive correlation was found between average tracking error for early periods of practice and reaction time. The correlations tend to decrease with more extended practice due to failure of the better subjects to improve beyond a certain point. It appears as if reaction time correlates with speed of learning rather than finished, learned tracking performance.

Individual Tolerance

One extremely important factor investigated by the Foxboro Company and contained in this report is the matter of tolerance as a limiting factor on tracking performance. It seems that each subject sets up a criterion of par for himself and is perfectly satisfied if he remains within the limits of his self-determined error range. This concept of an individual tolerance or par set up by the subject explains a number of facts which grow out of these experiments: (1) convergence of error scores toward a common value of most of the subjects with larger number of practice periods; (2) early appearance of final plateau in the case of the better operators or the rapid learners; (3) significant differences at the end of learning between subjects whose scores do not converge; (4) absence of work decrement in accuracy with prolonged periods of tracking. These results can be readily explained on the assumption that each operator consciously or unconsciously adopts a standard of performance and each is satisfied merely to maintain this standard. This can be accomplished under fatigue conditions by working harder than usual. Thus the aim in apparatus design should be to make the objective conditions such that as small an error will be tolerated as possible. It can be assumed that increased discrimination, motivation and adequacy of response may be accomplished through betterment of objective conditions. Any aid improving conditions of work, making work more comfortable, and bringing the task within the powers of the operator will increase efficiency. In the operation of tracking equipment, objective conditions surrounding visual presentation and handwheel control may be improved with consequent reduction in tracking errors. These investigators found considerable increase in accuracy through improvement in lighting and background conditions, for example.

10.2.2 Effect of Handwheel Speed on Accuracy

A third report from the Foxboro Company describes a series of experiments aimed at determining the relationship between handwheel speed and accuracy of tracking. (35) Fourteen previously highly trained subjects acted as operators and handwheel speeds varying from one RPM to 250 RPM were imposed

by the experimental conditions. These studies in direct handwheel tracking showed that the speed at which the handwheel is turned has a pronounced effect on both the amount and the character of tracking error. In general, and under a variety of conditions, high handwheel speeds were found to have a very favorable effect, on both accuracy and smoothness of tracking. For convenience in analysis, this series of studies was made with a course requiring constant handwheel speed for correct tracking. All conditions were held constant throughout the experiment, with only handwheel speed varying. The results were also confirmed by further study of runs on variable speed courses. These additional courses varied from a very easily tracked course, corresponding to a simple crossing target with the crossing point remote from the operator, to a very difficult course, resembling a plane flying an evading course at close range. In all four courses were used.

The results show that when the handwheel speed was reduced by 2.5 to 1, the error increased in the order of 50 per cent, while when the handwheel speed was increased, there was a corresponding decrease of about the same proportion. The operators appeared to experience no difficulty with the considerable accelerations which accompanied rapidly varying course, tracked at high handwheel speeds. It was only when surprise effects occurred that difficulty was experienced and this difficulty did not appear to be materially affected by the speed. The error curve drops steadily from 1 RPM to 50 RPM and remains constant at the low level through a wide range of between 50 RPM to the breaking point of the operator at 200 RPM or above.

10.2.3 Inertia, Friction, and Diameter

It was also found that friction in appreciable amount (2-pound friction was used), inconvenient position of handwheel, awkward hand grip and larger sizes of handwheel, all tended toward lower maximum speeds. Under good conditions, operators could track with the handwheel speed between 200 RPM and 250 RPM. The optimal speed band within which minimum error occurred extended well up toward this maximum speed in the case of every operator. Within this band, variation in speed had little effect. For most actual courses, the variation of handwheel speeds exceeds the width of the optimal speed band. Hence, minimum tracking error for the entire course will depend upon choice of a handwheel gear ratio which will permit a safe maximum turning speed at maximum course speed. That is, the highest required turning speed must be high but also attainable by all operators under the particular operating conditions. In the absence of data on the particular operating conditions, it appears safe to assume a maximum handwheel operating speed of 180 RPM. If a marked difference exists between slewing speed and maximum expected tracking speed, improved tracking may be expected by making the 180 RPM handwheel speed correspond to the maximum tracking speed with auxiliary provision for slewing.

Under the conditions studied, fatigue had little effect on tracking accuracy. Operators worked 15 minutes both with and without friction. The friction was applied directly to the handwheel, resulting in the same frictional torque regardless of handwheel speed, thus making work done proportional to the speed. Under these conditions, the decline in accuracy during 15 minute runs was at the low speeds but not at the high speeds.

Some studies were also made with untrained subjects. The results show that the advantages of high handwheel speeds are as great or even greater for untrained personnel as for skilled operators. In regard to the character of the curves of tracking errors, with the low handwheel speeds there are very wide swings of slow frequency with the operator seldom on target. As handwheel speeds are increased, the amplitude of these swings are steadily decreased while their frequency is increased. At the highest speeds, the pattern of tracking response shows very small variations actually corresponding to each revolution of the handwheel but almost invariably crossing the on-target lines. The importance of these differences in pattern with slow and fast handwheel speeds can hardly be overemphasized if the data are to be fed into a director, predictor, or computer. The results show that very different apparent target courses could be obtained from identical courses, depending upon the handwheel speed with which the course is tracked.

These investigators point out that, although these studies are of direct handwheel tracking, they appear to be applicable to certain conditions of aided tracking as well. It would appear that with larger time constants, of 2 or 3 seconds or more, the feel and

operating technique of direct and aided tracking are so nearly alike that the data on direct tracking studies are largely applicable to aided tracking without change. In particular, the lower handwheel gear ratios with the correspondingly higher speeds appear to favor greater accuracy in both cases. In aided tracking, the maximum speeds may not run as high as in direct tracking since an adequately low handwheel gear ratio with aided tracking may not require very fast turning even with the most difficult courses. Particularly, with aided tracking much more than with direct, the presentation of the data to the operator may prove the limiting factor on accuracy with a smaller proportionate effect from the handwheel condition.

A fourth report from the Foxboro Company is concerned with a more detailed study of inertia, friction and diameter of handwheel as they may affect direct tracking. (36) It was found that inertia, either in the form of a heavy handwheel or as flywheel effect inherent in or added to the moving system, reduced tracking error materially. In these studies a geared-up flywheel was used for low speeds, providing a moment of inertia at the handwheel shaft equivalent to a 55-pound ring of 20 inches diameter. At a steady handwheel speed of 2 RPM this resulted in a reduction of error of approximately 50 per cent compared with a lightweight bar handle type. At speeds up to 15 RPM lesser flywheel effects gave similar results. For speeds of 20 RPM and above, inertia effect was provided by a heavy handwheel 9 inches in diameter and weighing 9 pounds with most of the weight in the rim. Reduction of error of roughly 40 per cent for speeds up to 200 RPM were obtained with the heavy handwheel as compared with the light, bar type handle. The improvement was equally apparent for simple or variable courses. Even with a lot of inertia, it was only when the changes of direction and rate of turning were so abnormally great that the operator was physically unable to accelerate and decelerate fast enough that any detrimental effect occurred. It was also found that inertia had a very marked smoothing effect on the tracking performance. With inertia introduced, the operator was able to hold a more constant speed of turning when this was demanded, or to change turning speed more smoothly in following target courses.

The investigators point out that the nature of inertial effect in tracking is twofold. There is the definite mechanical effect of inertia of opposing variations of rotation, thereby smoothing the operating and reducing the tracking error. The second effect, less obvious but not less important, is the operator's reaction to the feel of a system having considerable inertia. Any tendency to change the rate of rotation is immediately sensed as a difference of force on the operator's hand and the change is avoided to a large extent, thereby giving a smooth turning speed. Without this tactual cue to the operator, changes in speed occur, building up errors which are revealed in the presentation and are then corrected. The feel of the turning speed of the handwheel provided by inertia permits the operator to sense rate rather than to rely on displacement error and so helps him to do a very much smoother and more accurate tracking job than was possible simply by watching the presentation. This reaction to the handwheel is equally useful when relatively smooth constant speed is needed to follow the target course or where speed variations are required by the situation. In this latter case the operator can increase or decrease the force on the handwheel to produce the necessary change of speed with the reaction still useful as a guide to the amount of force necessary to produce the required rate of change of speed. A trained operator takes advantage of the feel of inertia to obtain improved tracking on irregular courses without introducing the delay normally introduced by mechanical smoothing devices. This accounts for the fact that inertia is helpful even on a very irregular course up to the point where the force required to produce the necessary acceleration is beyond the physical limitations of the operator. Inertia is very easily added to any tracking system either by the use of a heavy handwheel, or, where speeds of rotation are low, by an added, geared-up flywheel. Inertia may be increased with beneficial effects up to a value where the force on the handwheel handle required to provide maximum acceleration is at least 10 pounds.

The results of these experiments show, on the other hand, that friction in any tracking system is definitely undesirable. Small amounts of friction are unavoidable in mechanical systems and the present tests indicate that the detrimental effects of these small amounts of friction are not serious, especially if there is a reasonably high inertia in the system. However, as the effective frictional torque at the handwheel increases, the adverse effect of the friction increases rapidly, producing large tracking errors.

This is particularly true at the lower speeds where the motion becomes decidedly jerky. The increase of friction, therefore, not only increases the tracking error but definitely increases the irregularity of the tracking.

Just as in the case of inertia, the effect of friction is twofold. There is the physical effect of a force roughly independent of the speed of turning which makes it physically impossible for the operator to rotate the handle smoothly. There is the additional fact that this frictional force tends to upset the operator's feel since the speed of rotation of the handwheel bears little or no relation to the force applied to it. Friction, of course, reduced the maximum speed the operator could turn.

A third factor investigated in these experiments was concerned with the effect of the size of the handwheel on tracking. Two handwheel sizes were tried, 4.5 and 9 inches in diameter. Both of these sizes are well within the reasonable range of handwheel sizes. As a result, both handwheels had a perfectly satisfactory feel. The difference between the two sizes did not make large differences in either accuracy or smoothness of tracking except when friction was added. However, as might be expected, the larger handwheel was somewhat better at the low speeds where the operator has difficulty in providing a smooth, uniform motion. The greater handwheel diameter provided a larger hand motion per revolution of the handwheel and hence contributed to smoother tracking. Similarly, in the presence of considerable friction, the larger handwheel was advantageous, since for the same frictional torque a handwheel of double the size required only half the actual turning force to move it. At the other end of the scale, for high speeds with light load and particularly for highly variable courses, the small handwheel was advantageous. In this case, the motion of the handle of the large handwheel approached or exceeded the physical ability of the operator, and so the smaller motion of the handle per revolution proved an advantage.

10.2.4 Single and Double-Crank Handwheels

A fifth report from the Foxboro Company deals specifically with the relative accuracy of handwheel tracking with one and both hands. (37) The results indicate that there was significantly superior tracking performance with a two-handed crank. The double-crank handwheel control has certain practical advantages in direct handwheel tracking, particularly where the load is appreciable and where the steadying effect from both hands on the wheel is useful, as under conditions of unsteady footing. Since the double crank may be operated with one hand for short periods without very great loss in accuracy, the double crank provides added freedom of action. Also, with the two hands in opposed positions the operator can apply more than double the torque he could apply with a single handwheel. This is useful in overcoming friction and it also makes possible the use of larger amounts of inertia to the improvement of smoothness and accuracy of tracking. A double crank has the disadvantage that it must be mounted almost directly in front of the operator, low enough so that it does not interfere with the operator's vision, and high enough to be easily reached. In contrast, a single handwheel can be operated satisfactorily within a wide range of positions relative to the operator.

In the present tests the double crank handwheel had an advantage of 22 per cent in tracking accuracy over the average of the single handwheels without frictional load for five operators. With frictional load the advantage was 25 per cent. For these particular conditions the single handwheel with its axis at right angles to the direction in which the operator was facing showed an advantage of 10 per cent without friction and 18 per cent with 7 pounds friction, over the single handwheel with its axis parallel to the directions in which the operator faced. Again the pointer matching was the form of presentation and unidirectional courses were employed.

10.2.5 Target Speed

Still another Foxboro study analyzes the effects of target speeds and rates of turning on accuracy of direct handwheel tracking. (219) It was found on tracking a moving target with a hand crank, over a wide range of conditions, that tracking accuracy can be improved both by reducing gear ratio and by increasing the crank radius to increase the hand motion corresponding to a given movement of the presentation. Accuracy of tracking decreases with increasing speed of target, but not in direct propor-

tion. For a given crank radius the gear ratio which gives best results at the maximum or limiting speed also gives better results at all lower target speeds than any other ratio which could be used at the limiting target speed. From these results the following conclusions are drawn:

1. Accuracy of tracking is greater with hand and arm motions near the operator's limit of turning, whether induced by lower gear ratios or larger sized handwheels.
2. Gearing down to increase accuracy is about 1.5 times as effective as increasing size of handwheel.
3. The maximal target speed to be followed limits the gear ratio and radius of handwheel since turning speed must be kept below the breaking point.
4. In the present experiments, optimal size of handwheel was found to be at least 8-inch radius, which was the largest employed. Since the angular breaking speed is reached sooner with this size handwheel than in the case of smaller, cranks of not more than 6-inch radius and not less than 2-inch radius are recommended for maximum range of good turning speeds.

10.2.6 Magnification of Data Presentation

Another Foxboro Company report deals with the improvement in direct, aided, and velocity tracking through magnification of data presentation. (220) In this study improved tracking accuracy from higher magnification of presentation is of primary interest in both direct and aided tracking by means of handwheel-operated control. The results indicate that tracking accuracy is definitely increased with higher magnifications in the case of direct tracking of a constant, unidirectional course, and to a greater extent in difficult courses requiring high velocities and accelerations as well as reversals in turning. Through the introduction of simulated noise, it was found that when magnification increases jitter and unsteadiness to the point where the presentation is bad, lower magnification is preferable in keeping with the principle that elimination of eyestrain improves overall tracking. Magnification of presentation data was found to be of greatest benefit with aided and velocity tracking probably because operators are able, by means of aiding, to exercise better manipulative control in accordance with what they see. Finally, it was found that individuals approaching tracking for the first time do better with higher magnifications immediately and that change in magnification factor during training expedites learning to track. For the aided tracking situation with aided constants varying from 0.02 to 4.5 seconds the errors curves are parallel and the errors are reduced to about one-third for 4x over unit magnification.

10.3 EXPERIMENTAL TRACKING TRAINERS

A tracking trainer was devised at Tufts College as an experimental instrument for studying the tracking problems which occur in the operation of the Army Directors M7 and M4. This instrument is completely described in a report. (87) It is similar in external appearance and general dimensions to the Director M7, and duplicates those characteristics which are essential to the tracking operations, such as, positions of handwheels and eyepieces, handwheel ratios and torque, rotation of instrument case and telescopes, and the like. The instrument is provided with its own internal target which is an illuminated photographic slide. The position of the target is controlled by cams which can be made to duplicate any desired aerial course. Hence, true target position is always known. Courses can be tracked by both the azimuth and elevation trackers simultaneously or the instrument can be used for testing either tracker alone. An ink-recorder in the trainer provides a continuous record of the errors made by each of the two operators. In addition, a clock score is obtained which represents directly the amount of time "off-target". These immediately available measures of performance are useful both from an instrumental and a research point of view.

Another report outlines the results of the use of the Tufts Tracking Trainer as a selection and training device for trackers on the M7 Director. (88) Studies of both reliability and validity were obtained. Two groups of 16 untrained men were matched for initial tracking ability on the basis of a pretest on the Tufts Trainer. Each group was given a total of three hours of distributed tracking practice, one group on the trainer and the other on the M7 Director. Final tests for both groups were then conducted on the director during which photographic records were taken of tracking performance. The average error scores obtained from the pretest and final test courses tracked on the trainer were found to be very reliable. Scores from a pretest of

6 minutes duration were found to predict success in tracking on the Director M7, with a degree of accuracy high in comparison to the general run of selection tests in use in the Services and in industry. It was also found that 3 hours practice in tracking on the trainer resulted in at least as accurate tracking on the director as the same amount of tracking on the director itself. Although the average decrease in error resulting from three hours training showed improvement from 3.95 mils to 1.51 mils, nevertheless the learning curve indicates that learning was still not complete at the end of this period of training.

10.3.1 Antiaircraft Tracking

Some special studies of antiaircraft tracking were performed at Iowa State College in an attempt to consider the human operator in his servo capacity, with special emphasis on the design of the associated apparatus by which the servo action is obtained. (315) A job miniature was produced both with direct and aided tracking. A handwheel, single and double finger knobs were introduced as tracking controls. The learning curves indicate that the tracking error for handwheel is largest followed by single knob and lowest with double knob controls. Hence it would seem that the use of two hands, such as one employs in the double knob control, gives better and more continuous control. An aiding ratio, under these conditions of experiment, with an aiding value of 0.071 seconds proved to give a smaller tracking error than one of 0.125 seconds. Other factors, such as friction, were also studied. Some psychological factors of the operators were also investigated.

From these results the investigators conclude that subjects should be selected as trackers after considerable practice on the actual field apparatus or a good job miniature. It is believed that a selection program outlined should yield 10 per cent of the original number of candidates who could track with errors well under 40 per cent of the original group average. Double fingerknobs of 2-inch diameter are distinctly better as manual controls than the handwheels now in use, giving only about 65 per cent as much error. This superiority persists with a loading resistance of 1500 gm—cm. If an aided rate follower is used, the time constant seems quite independent of the angular velocity at crossover and of the type of manual control used. The most advantageous value seems to be R = 0.17-0.20 seconds, which is near the Kerrison value.

In a supplementary report for Iowa State College (316) special attention is given to problems of following a target with acceleration and of magnification. It was found that the use of a component of acceleration considerably reduces the tracking error. The most advantageous direct component is fairly independent of the accelerational term. It was found, also, that an increase of magnification from 30x to 75x was not helpful while a reduction to 12x was definitely a hindrance.

A second supplementary report from the Iowa State College contains results on two additional tracking problems. (317) The first of these indicated that a 4-, 6-, or 10-week layoff did not affect tracking accuracy, provided the subjects had been previously very highly trained. No differences were discovered when trackers used binocular or monocular vision.

10.3.2 Comparison of Sights for Slewing and Tracking

At the request of the Naval Bureau of Ordnance, the Foxboro Company made a comparative study of the slewing times and of tracking errors with several kinds of sights used with small caliber antiaircraft weapons. The first report deals with the comparative slewing times with optical ring, telescopic, and ring-post sights. (222) The results indicate that the optical ring sight has a marked and highly statistically significant advantage in the time required to get on target. The length of the slewing paths varied from 5 degrees to 45 degrees and also varied greatly in direction. Six inexperienced operators were used in the tests. It was found that differences in slewing time as large as 0.5 second appear with the use of different types of sight. Quickest slewing, on the average, was found with the optical ring sight 1.44 and 1.26 seconds for azimuth and elevation respectively, and slowest slewing for the telescopic sight—1.87 and 1.75 seconds. The ring and post sight falls between these two on speed of slewing after initial practice, during which ring and post is about as slow as the telescopic sight. Slewing distance, obviously was found to be important in determining slewing times, there being progressive increase in time with increase in slewing distance. However, the time increment, within the limits used, is not as great as the distance increment since the increase in time is only

about one-third whereas the increase in distance is ninefold. Since the reaction time merely to start the slew at a given signal is only about one-tenth the total slewing time, most of the time spent in slewing must be taken up with finding and getting on target.

In a second report from the Foxboro Company, two additional sights, a smaller optical ring and an illuminated ring sight, were added to the comparison of slewing times. (224) The present tests in general confirm the previous findings: slewing times are shortest with optical ring sights, whether large or small radius, longest with ring-post and telescopic sights, and intermediate with the illuminated ring. The two sizes of optical ring gave practically identical results so far as slewing time is concerned. The difference between the best and poorest sights for slewing amounts to as much as one-half second which means from 33 to 50 per cent of slewing time, depending upon the time taken as base. Comparisons of the sights with light and heavy mountings showed no differences in slewing time due to inertial effects.

The Foxboro Company reports data from an experiment to test the accuracy of tracking with illuminated, telescopic, ring-post, and optical ring sights. (223) Under the conditions of these tests, the 10 mil optical ring, telescopic, and illuminated sights were equally accurate, but superior to the 50-mil optical ring and ring-post sights. The 50 mil optical ring is, however, superior to the ring-post sight. A bright sky background and moderately difficult tracking course were characteristics throughout these experiments. The average tracking errors in mils were between 2.8 to 3.1 seconds for the three best sights, 3.8 for the 50 mil optical sight and 7.6 for the ring post sight.

A second Foxboro Company report summarizes additional tracking experiments using the same five sights. (225) The previous report dealt with experienced observers working in bright daylight. The present report is concerned with the accuracy of the same sights when tracking under two further conditions: (1) with experienced operators in simulated twilight as well as daylight, and (2) with inexperienced operators in daylight only. The results of this experiment confirm the previous finding that for trained operators the 10-mil optical ring sight, the telescopic and illuminated sights yield equally accurate tracking. Both studies and all operators agree in showing the 50-mil optical ring to be less accurate than the 10-mil optical ring but superior to the ring-post sight, while the latter in turn is much the poorest of all. The ring-post sight proved to be even worse with the untrained than the trained operators, giving an average tracking error of 13.8 mils. Under the simulated twilight, with low illumination of less than 1 foot candle, the tracking with the 10-mil optical ring was adversely affected, but this was probably because the particular sight used in these tests lacked a clear central area. Only the telescopic sight proved to be significantly better than the other sights under the low illumination. The ring-post was significantly worse than all the other sights under the low illumination. The results with untrained operators indicate the need for additional practice to attain comparable accuracy when using sights which lack a center dot. The optical ring sights, however, do not require much extra practice to compensate for lack of center dot and thus that lack is not so serious in their case.

Chapter 11

EFFECTS OF HAZE AND OF ATMOSPHERIC SCATTERING

11.1 INTRODUCTION

It is a generally recognized fact that objects further away from an observer seem less clear and distinct than objects which are closer. This effect may be seen monocularly and, indeed, is one of the cues used in judging distance. The effect is due to the fact that there is more intervening air between the observer and the distant target. This effect is well known to psychologists and has been called aerial perspective. It is a technique universally employed by artists to accentuate apparent depth in their paintings. A corollary of this situation is that, if two objects are the same actual distance from the observer but one is clear and the other indistinct, the clear object will seem to be apparently closer to the observer.

Such a situation is found in the range finder when the weather conditions are such that haze intervenes between the observer and the target. In this case the reticle will appear clear while the target appears hazy and indistinct. It has been found that this monocular cue may have an effect upon the binocular stereoscopic judgment and hence give a false range. This fact is recognized in the Navy by the determination of what has been called Curve B. It was known that the correction necessary to obtain true range might vary, not only with the distance of the target, but also as a function of the particular range finder and of the particular operator. Methods are outlined for determining the influence of each instrument and a corrected adjuster setting is introduced to overcome this error.

Some field studies were carried on at the Princeton Laboratory at Fort Monroe to study this effect. The effect of weather factors on the RCS setting used is reported. (373)

Another Princeton Laboratory study was made to determine, for the stereoscopic height finder when employed as a range finder, (1) the extent of errors in range determinations on fixed targets; (2) the amount of errors arising from certain selected definite causes for which calibration was possible; (3) the amount of residual error which cannot be corrected by calibration; and (4) the causes responsible for this residual error. (26) In a typical experiment ten observers made a total of 110 range determinations (each the mean of ten single readings) on five targets, using three different instruments. It was found that the standard deviation of these determinations (i.e., the standard error of a single determination) was 15 UOE. In this experiment, systematic differences as great as 17 UOE were found between instruments; as great as 16.5 UOE between individual observers, and as great as 9 UOE between targets. The elimination of these systematic differences left a residual variation, expressed as the standard error of a single range determination, of about 6.25 UOE. These results are typical of a much larger body of data, taken at Fort Monroe, on 20 highly trained range finder observers with a total of about 30,000 individual readings. The causes of these errors show that errors in RCS account for at least 1 to 2 UOE and that this is partly due to the operator's method of making the setting. Errors of this magnitude are reported in other experiments. It appears that certain observers gave reasonably regular curves but that there are marked differences in observers, both in the slopes of the curves and in the scatter of the individual readings. It was also evident that, for some observers, the slopes of the correction curves differ with different instruments. Another report gives a new formula for converting range errors into UOE which is a better approximation, particularly at the longer ranges, than the one commonly used. (426)

One extremely interesting and important research by the Fort Monroe Princeton Laboratory had to do with the changes in Curve B with time. (427) Data were calculated for three test observers over a long period of time and after this large amount of practice, with one exception, there is no longer any indication of anything but a flat correction independent of range. These data are too small to be a basis for generalization; they are, however, highly suggestive. Because of the very large amount of practice of these observers on fixed targets, it seemed reasonable to suppose that their accuracy had improved. Hence it

seems reasonable that, insofar as Curve B is a result of conflict between stereoscopic cues and other cues, this continued observation should result in improving the operator's ability to make judgments solely on a stereoscopic basis and to ignore the monocular cues of aerial perspective. In other words, Curve B may be trained out of some observers by continual practice.

11.2 STUDIES ON EFFECT OF HAZE

In order to study the effects of haze under more controlled conditions, a method of producing simulated artificial haze in controlled amounts was developed at the Princeton Laboratory at Fort Monroe. (428) A small amount of data taken in this manner were consistent with the belief that Curve B can be explained in terms of aerial perspective. At least it was determined that range settings became consistently longer with the introduction of haze. The description of a model of an instrument for producing simulated artificial haze is reported.

11.2.1 Loss of Contrast

A final experiment on this topic at the Fort Monroe Princeton Laboratory has to do with diffuseness and lack of contrast in the atmosphere and their possible effects on range reading. (429) This is a theoretical discussion of the effects of atmospheric scattering as against poor seeing, which is believed to result from more or less random fluctuations in the refractive index of portions of the atmosphere due to the passage of waves of pressure or temperature. The conclusion drawn from this study is that the effect of atmospheric haze was found to be concentrated on the production of loss of contrast rather than of diffuseness. The opposite is true of the effect of poor seeing. It is pointed out that the meteorological correlation between these effects might easily lead to their confusion.

One other field experiment, which has some interest for coincidence types of instruments, was reported by the Howe Laboratory of Ophthalmology. (313) In order to obtain field data on real haze, a larger contour break apparatus was constructed with a target face 5 feet square. Three degrees of contrast approximately 85, 50, and 25 per cent were available. Observations were made through 12x binoculars and the apparatus was set up at several beaches and other observation points. A typical result shows that at a distance of 5 miles a break subtending an angle of 12.7 seconds of arc was actually observed whereas it was calculated that a break of 10.8 seconds of arc would have been expected had the target been viewed through a vacuum at this distance. In this instance, the effect of the atmosphere on contour break appears to be very slight. Loss of contrast was quite noticeable and at distances beyond 5 miles the target as a whole could not be distinguished from the shore background. There were also results which indicated that stereoscopic accuracy on large high contrast targets was also relatively unaffected by distance as long as the targets could be seen. Observations taken on quite hazy days showed more marked deterioration of performance. Observations appeared to be more variable and the deviation from linearity less marked away from the sea, possibly because of smoke.

A highly controlled and carefully conceived series of experiments to determine the effects of haze and of other factors which might produce constant errors in range were performed at Ohio State University. Three aspects of haze were studied, loss of contrast of target with background, blurring of target outline, and the chromatic difference of target and reticle backgrounds.

In regard to the effects of loss of contrast between target and background, the measurements indicate that there may be a Curve B effect (increase in apparent distance of target) in some subjects when the contrast is reduced to only 50 per cent. (336) Almost all subjects show the constant error when the contrast is reduced to near threshold values, as would be the case when ranging on objects near the visual range. In general, the constant error increases as an exponential function of decreased contrast. All subjects indicate an increase in the apparent distance of the target when conditions of seeing are made more adverse, by reducing the brightness level in addition to a reduction in contrast. The loss of contrast is effective for a number of relations of target, background and reticle brightness, simulating various conditions of ranging. It was found that the effect of loss of contrast can be reduced to some extent by training, especially in those individuals who show the effect at relatively high levels of contrast. How-

ever, the nature of the relation between contrast and range error remains much the same.

11.2.2 Blurredness

In studying the effects of blurredness, it was found in the experimental situation that it was possible to produce a Curve B effect by blurring the edge of the target. However, calculation of the effect of fog on the blurredness of a real target indicated that the atmospheric scattering due to fog is usually a factor in reducing effective contrast rather than actually blurring the brightness contour which defines the target. Therefore, it is concluded, blurredness as such is probably not a significant aspect of the constant errors introduced by fog and haze. Of much greater importance is the loss of contrast between target and reticle. In another report, there is developed in detail a theory of the effect of atmospheric scattering and absorption of light by the atmosphere and the effects upon the appearance of a dark object against a sky background. (335) This hypothesis forms the theoretical basis for the experiments reported above.

As a result of these experiments, the Fire Control Division of NDRC made the following recommendations. (14) Variability in the personal constant error shown with loss of contrast makes it difficult to correct for this factor. Nevertheless, if it is found that the height and range finder must be operated under conditions of reduced contrast, it would be worth while to determine the extent of the effect for each operator and to measure the contrast between target and sky (or other background) directly at the time of making the range, and thereby make possible a correction for this factor to determine true range. This could be accomplished perhaps by mounting a light meter or other device for measuring contrast directly on the range finder.

In a further laboratory experiment at the Ohio State University it was demonstrated that the extent to which blurredness impairs the sensitivity of a difference in distance is dependent upon the size and shape of the target. (327) In the case of a large object, there is no loss in contrast between the center of the blurred image of the target and the background, whereas, in the case of narrow lines, the contrast decreases in inverse proportion to the addition of lens power to the distance correction, in the experimental instrument. It is pointed out that the width of the reticle marks in the M1 Height Finder are in the class of objects which would be subject to a loss in contrast as a result of increased blurredness. This indicates that great care must be exercised in the focusing of the eyepieces of the instrument to obtain sharp and clear reticle patterns during ranging. On the other hand, a bomber at 10,000 feet is in the class of objects which would not be affected by small degrees of blurring introduced by errors in the optical system, reduced apertures, and improperly focused eyepieces, so far as contrast with the background is concerned. Smaller planes at greater distances would certainly fall at the borderline between these two classes of objects.

Following the suggestion of the NDRC report, Ohio State University devised a combination tracking telescope and contrast meter for a stereoscopic range finder. (333) A vectographic reticle was devised for rotating a vectographic film in front of a constant polarizing disk in connection with the crossed lines of a tracking telescope. After trial of several modifications, this was abandoned and a 12-spot reticle was developed instead. In the reticle of the tracking telescope to be used for azimuth tracking, 12 circular dots are placed, corresponding to the hour positions on a clock face. These are produced photographically and transmit amounts ranging from about 94 to 4 per cent of the light transmitted by the clear portion of the reticle. Hence the contrast of these spots varies from 6 to 96 per cent. The azimuth tracker merely has the task of determining which spot most closely resembles the target. Two reticles were prepared. Detailed descriptions of their manufacture, preparation, and mounting and use are given in the report.

The Ohio State Contrast Meter was given field trials at the Naval Training Schools at Fort Lauderdale, Florida, and the results are reported by the Applied Psychology Panel. (93) This report concerns the problem of the change of range error occurring as a result of change in the contrast made by an aerial target with its background when seen through a stereoscopic range finder. In order to test the hypothesis that range error changes in a positive direction whenever contrast of target with background becomes poor, ranges on aerial targets were taken by 42 observers in Class 8 at this station. Simultaneously with the ranges, contrast readings were made by means of the Ohio State Contrast Meter, and reference ranges were determined by means of Mark 10 radar. From these reference ranges, range error was computed.

Two analyses of the data were conducted, one for

the entire group of 42 observers, the other for a group of 11 men who had recorded 10 or more ranges at both high and low extremes of contrast. In neither case did a comparison of the range errors at high and low contrast show a statistically significant difference. It is true that the average curve of range error runs from a slightly minus to a somewhat plus value (−0.1 to +2.5 UOE for the best 11 observers). Still, the variability of individual or even of average observations of the different observers makes this trend statistically unreliable. Because of the possibility that a significant effect of contrast on range errors had been masked by the effect of a third variable, namely range, a further analysis was made. This indicated that such a masking effect was not present for the group of 42 observers. If the range variable had any effect, it was to increase rather than to decrease any tendency toward positive range error due to low contrast.

The actual contrast which the aerial target made with its background varied radically, in a large proportion of the cases, over a short run of 140 seconds. This would make any possible correction for contrast very difficult even if the necessity for such correction could be shown. Under conditions of contrast variability less subject to quick changes than those of this experiment, some correction might be applied. The contrast conditions under which the data for this report were collected show no significant effect on range error, and allowed no possible correction to be calculated.

11.2.3 Chromatic Dispersion of the Human Eye

Ohio State University also performed a very carefully controlled laboratory experiment on the chromatic dispersion of the human eye and its possible influence on stereoscopic range finding. (334) Measurements were made of the ocular chromatic dispersion for colored targets with a wave length difference of 93 millimicrons. The values ranged, for the 13 subjects, from 102.4 to −19.7 seconds of arc. Measurements on two individuals indicate that the chromatic dispersion may change by as much as 28 seconds when the field brightness is changed to produce a pupil constriction of the order of 1 to 2 mm. The authors believe that this change is probably related to eccentric constriction of the pupil. In a situation designed to simulate the chromatic aspects of haze, constant errors were found, apparently dependent on the color difference of 45 millimicrons between target and reticle backgrounds. For the same 13 subjects, the values ranged from 54.8 to −25.8 seconds and correlated fairly well with the measurements of binocular dispersion indicated above. Finally, calculation of the difference in color of the target and reticle backgrounds under haze conditions indicate that a color difference as great as that used in the experiment simulating haze effects could be present and that, therefore, the ocular chromatic dispersion might be an important factor in producing constant errors in range finding.

As a result of this experiment, the Fire Control Division of NDRC made the following recommendation. (13) It was recommended that measurements be made, using a simple portable apparatus, of the ocular chromatic dispersion of a group of range finder operators. These data could be compared to the operators' constant errors in haze and fog to determine whether the dispersion factor is influential in producing these errors. If such a relationship is established, it would be a simple matter to screen out operators, prior to training, who show a large amount of chromatic dispersion. There is no evidence that this recommendation was ever adopted by either Service.

A further study of the relation of chromatic aberration and dispersion of the eye to the blurredness of an object seen through the M1 Height Finder was performed at Ohio State University. (326) This is a theoretical discussion of axial chromatic aberration and chromatic dispersion of the eye as might be found in the use of this instrument. Several available methods for overcoming the influence of this factor are outlined. It is pointed out that chromatic dispersion may be controlled by (1) decentering the eye with respect to the exit pupil of the instrument; (2) the use of a filter that is relatively monochromatic; (3) changing the size of the exit pupil; and (4) undercorrection of the eyepieces.

An experiment was performed at Camp Davis to study Service personnel in regard to chromastereopsis and to test several instruments to determine the amount of individual influence by several devices which were developed. (331) Direct measurements were made with a rotary dispersing prism which is described in the text. An indirect measurement of chromastereopsis was made by comparing the interpupillary distance with the separation of two slits required to compensate chromastereopsis. Pooling the results of several groups of 30 subjects each (all

students at the Stereoscopic Height Finder School) the average for chromastereopsis is 31.7 seconds of arc. Measurements found with the split gauge are on the average about 0.5 mm smaller than the average interpupillary distance as measured with the Shuron IPD gauge used in connection with a mirror. This corresponds to about 116 seconds of chromastereopsis. Inasmuch as the majority of the operators show a definite tendency to a positive type of chromastereopsis, most of them would have to be screened out if stringent tolerances were placed on chromastereopsis. It seems more desirable, therefore, to provide compensation for chromastereopsis by making use of various accessories for the range finder than to try to screen out persons who show an appreciable amount of chromastereopsis. However, chromastereopsis varies too much from individual to individual to assume a fixed allowance for all observers. The several methods for compensating for chromastereopsis are discussed, as well as the chromatic properties of the several parts of the standard range finder.

11.2.4 Intermittent Visibility of Low Contrast Targets

Ohio State University has also performed a very careful experiment to determine the effects of the intermittent visibility of low-contrast targets on stereoscopic range measurements. (325) With targets of low contrast, they have demonstrated that there are periods during which only one eye sees the target, because of intermittent activity at the peripheral levels of the visual apparatus. During such periods of monocular visibility, it was found that there is a predominant tendency to see the target as lying behind the plane of the reticle. Unfortunately the observer is not aware of such periods of monocular vision when using a binocular instrument. The introduction of intermittent exposures to alleviate this situation proved only moderately successful. However, the situation occurs only with targets of very low contrast. This effect is produced because the activity of each eye is independent of the other. The most likely explanation of the fact that the target is seen more remote than the reticle during the times of monocular viewing is that the reduced contrast of the target serves as a cue for seeing it at an increased distance, and this cue is allowed to have full sway when the stereoscopic cue is removed.

An investigation was made of the possibility of extending the range for making usable range measurements by resorting to intermittent exposures. The investigators designed a clever apparatus for this purpose which might have been incorporated in a range finder. The principle behind this scheme was to take advantage of the capacity of a new onset of stimulation to initiate a visible impression of a faint target which tends to disappear periodically when the exposure is continuous. This scheme also had the advantage of synchronizing the effects for the two eyes. Although intermittent exposure has the effect of such synchronization, a level is soon reached at which, with intermittent exposures, the target is no longer visible with every flash. When this level is reached the same situation obtains with intermittent exposure as with continuous exposure in that, with some of the flashes, the target is seen with only one eye. An exposure of at least 1-second duration is indicated as the minimum that can be tolerated for making stereoscopic measurements. However, increasing the length of the exposure would introduce other complicating factors, because the natural bracketing rate of a range operator is about 1 to 2 seconds per cycle. In this connection, attention is called to the fact that the precision of settings at higher levels of contrast is impaired by the use of intermittent exposure, which is effective only at low levels of contrast.

Finally, the group at Ohio State University investigated the relation of stereoscopic acuity to accommodation and vergence. (328) These investigators demonstrated that the maximum stereoscopic acuity occurs in the region of zero vergence and small accommodation changes. Explanation of this state of affairs is made in terms of the blurredness of the retinal image. Since the axes of the range finder are adjusted for substantially zero convergence, it follows that range finder operators will not reach their maximum level of stereoscopic acuity if they have a substantial amount of heterophoria, so that they are required to exert substantial vergence effort.

The last several papers from Ohio State University were abstracted in a report to the Services issued by the Fire Control Division of NDRC. (32) No recommendations were made to the Services on the basis of these reports. Although some of these studies demonstrated sources of error in the use of the present stereoscopic instruments, it was believed that the magnitude of such demonstrated errors was relatively small compared with other known factors.

Chapter 12

MISCELLANEOUS FACTORS OF OPERATION

12.1 CONTINUOUS CONTACT VS BRACKETING TECHNIQUES

At Tufts College a laboratory study was made to determine the cause of the phenomenon of constant error, the tendency to set contact with the target either in front of or behind the fiducial mark. (558) Four bracketing methods were employed: (1) Subject was instructed to move target so that he obtained a break on the opposite side from that on which he started, then to break on the same side, then to set the midpoint of this interval. Only two changes in direction of movement of the target knob were allowed. (2) The subject was instructed to move the target so that he obtained a break on the opposite side and then to make contact by reversing the direction of movement of the target knob. Only one change in direction of movement of the target knob was allowed. (3) The subject was instructed to make contact by moving the target knob in one direction only. No changes in direction were allowed. (4) The subject was allowed to use any bracketing technique he cared to. Unlimited time to make contact was allowed. Six highly trained subjects were used on the Tufts Stereoscopic Trainer. The results do not indicate any statistically significant differences in constant error or in variability score among any of the four methods; unlimited bracketing is no better than direct contact for the fixed targets which were employed. The investigators conclude that height and range finder operators, after training, should be encouraged to set contact directly without bracketing. This procedure would cut down on dead time without, apparently, significant loss of precision in setting contact for fixed targets.

A laboratory study was conducted at the Howe Laboratory to determine the effectiveness of make-and-break and continuous tracking in range at various rates of change of angular disparateness. (308) A complicated apparatus is described in the appendix of this report. With this apparatus it was possible to simulate in five short ranges from 25,000 to 5,000 feet and hence simulate the path of an incoming target diving at apparently 300 knots. The ranging mechanism was built so that it essentially reproduces the regeneration effect of a Mark 42 Range Finder employed in conjunction with a Mark 1 Computer and rate-of-change-of-range receiver. Without the regenerative feature, results were made for five trained subjects making contact; 1 front to back, back to front, and continuous tracking. Subsequently various amounts of regeneration were introduced into the experimental situation.

The results indicate that, as the amount of regeneration increases, thereby reducing the rate of change of disparateness, the advantage of front-to-back contact decreases until finally continuous tracking may become slightly superior. The investigators conclude that if make-and-break contact is employed on an incoming course, greater accuracy will result if front-to-back rather than back-to-front contact is employed, particularly when the rate of change of disparateness is high, before regeneration is made available. After a rate has been established and regeneration is adequate, alternate front-to-back and back-to-front contacts will tend to reduce constant range errors. However, this is not to be taken to mean that this method of ranging is better than continuous tracking employed throughout a dive, because in the discontinuous method rate control can be introduced only on range finder signal, while rate control can be introduced at any time during continuous tracking. This Howe Laboratory study applies only to the special case of a fast incoming diving target when the Navy type of regenerative range control is available.

A laboratory study of maintaining contact on a moving target with a stereoscopic range finder is reported from Ohio State University. (332) This investigation is a comparative study of the methods and accessory devices which can be employed with the range finder to help maintain stereoscopic contact on a moving target. The report discusses the different types of range-compensating devices which are or might be used with stereoscopic range finders. Such a device would provide an automatic adjustment of the range-measuring mechanism as the plane changes range, so that the residual apparent movement in the fore and aft direction is slow and the amount that the stereoscopic observer has to manipulate his controls is reduced to a minimum. Such devices are the automatic compensation for rate of change in range in the M1 Height Finder and range

compensation provided by the control knob. Other types of possible rate-compensating devices are illustrated in the text as well as a device, used experimentally in this study, to provide automatic bracketing throughout observation of the target. A detailed description of the automatic bracketing apparatus is given in the text. This is accomplished by two rotating prisms, base up and base down which change the apparent position of the target as they rotate. Various cycle speeds and amplitudes and various degrees of contrast between target and background were employed. From the data of preliminary experiments, it can be inferred that when the target contrast is low, and the amplitude of excursion is small in the automatic bracketing situation, there must be a limit below which the duration of the cycle cannot be reduced. But when the contrast is high and the amplitude of excursion is large, no explanation can be found in the flash exposure data for the periodic disappearance of fore and aft movement which occurs in automatic bracketing as the cycle frequency is increased, nor can an explanation be found for the final complete disappearance of fore and aft movement at higher frequencies. In the flash exposure experiment, the frequency of exposures was kept constantly low at one exposure every 3.96 seconds. Therefore the investigators believe that the interval between exposures is a determining factor in the situation in addition to the length of exposure.

It was decided that experiments with cycle frequencies higher than 30 per minute were useless. In a second set of experiments this frequency was employed as a standard. The results indicate that a superior performance can be obtained with intermittent rather than with continuous exposure. Not only is the minimum perceptible amplitude of excursion larger in the case of continuous exposure but it was found that the experiment had to be discontinued at higher levels of contrast than in the case of intermittent exposure. Also, except at the intermediate levels of contrast, the minimum perceptible range of movement is consistently greater when measured with the range decreasing than with the range increasing. A comparison is made of the amplitudes of hand and automatic bracketing necessary to produce a just noticeable difference between target and reticle. It was found that the amplitudes required for a minimum perceptible bracketing movement are about the same in the case of hand bracketing as in automatic bracketing. In the case of normal hand bracketing in which the subject is permitted to move the target image out beyond the plane of the reticle, the amplitude of the bracketing excursion is much greater than when it is limited to points just perceptibly in front of or behind the reticle. This means that setting the target at supraliminal distances in front of or behind the target gives the subject a more certain feeling that he is moving the target equal distances to either side of the reticle. It is important to note that hand bracketing movements are of less frequent occurrence than automatic bracketing movements, especially at the lower levels of contrast. This probably means that the automatic bracketing technique was penalized, in this experiment, by using a higher cycle frequency than that employed in the hand bracketing technique. In other words, the experiment involving hand bracketing technique can be regarded as an experiment to determine the most satisfactory cycle frequency to use in the automatic bracketing situation. There is certainly no limitation to the subject's faster manipulation of the knob and the frequency of bracketing movements is probably dependent upon the visual perception of the bracketing movement. The result might be taken, therefore, as evidence that if automatic bracketing were employed in connection with a range finder, the cycle frequency should be somewhat lower than 20 per minute. Indeed, the cycle frequency probably should be variable to correspond to different degrees of visibility of the target.

Another section of this report has to do with range measurements on a stationary target with automatic bracketing. A cycle frequency of 30 per minute was employed. The results indicated no appreciable difference with and without automatic bracketing. Still another section deals with the detection of slow drifts, using continuous contact and automatic bracketing. No considerable differences were detected between the two techniques although automatic bracketing gave slightly better results than continuous contact. The records correspond closely in shape to the true course of the target but show a certain amount of lag and also a certain amount of lateral displacement, which indicates a constant error in the range measurements.

The investigators conclude that if automatic bracketing is used at all, it ought to be used in conjunction with intermittent exposures. The maximum cycle frequency that can be employed with such a device is about 30 per minute or even somewhat

lower. The amplitude of excursion with the automatic bracketing should be variable depending upon the visibility of the target but for a high contrast target the minimum excursion should be at least 60 seconds. If the frequency is made greater or the amplitude smaller, the apparent fore and aft movement tends to cease periodically or completely after one fixates the oscillating target for a period of time. The broken contact method, if used at all, has to be used in conjunction with an interpreter-controlled compensating device, and hence if an automatic or observer-controlled rate compensating device is used, either continuous contact or automatic bracketing would have to be employed. The continuous contact technique, automatic bracketing, and the broken contact techniques have been compared with respect to their capacity for detecting slow drifts. The data relating to lag, departure from true range, precision and the like do not show that any one of these methods is markedly superior to the other two.

Two field studies are reported by the Princeton Laboratory at Fort Monroe on this general topic. The first of these has to do with the distribution of range finder readings when different methods of contact are used. (392) The data is from five observers on one course with fixed target. Last motion increasing and last motion decreasing were employed. The distribution of readings was not significantly skewed and the histogram was flat topped for the last motion increasing series. For last motion decreasing, the histogram was significantly skewed toward the shorter range and was significantly peaked in form. Similar results were found for the second Princeton Laboratory study at Fort Monroe. (422)

A laboratory study was made at the Howe Laboratory comparing the accuracy of stereoscopic ranging on different types of targets. (312) Twenty totally untrained subjects and six observers previously highly trained only on difficult moving targets were tested with five different types of targets. Fixed targets were employed and simulated dives at 300 knots with 0, 150 and 250 knots regeneration. A simplified stereoscopic training instrument was used which is described in an appendix of the report. It was found that the average performance of all the observers trained from 3 to 6 months previously on difficult targets is about 0.5 to 9 UOE better on all types of targets than is the average performance of all the untrained observers. These results demonstrate that training on difficult targets is immediately transferable to easy targets, moving or fixed, even though long intervals of total lack of practice intervene. For one continuous tracking series the worst trained observer is in eighth place of the 28 observers with an average error of 8.5 UOE while the range of error for all subjects runs from 3.9 to 42.8 UOE. In another series employing make-and-break contact, the worst trained observer is in tenth place with an average error of 7.1 UOE while the range of error scores for the whole group runs from 3.1 to 40.2 UOE. In both series, previously trained observers are in the first four places.

12.2 FOCUSSING OF TELESCOPIC EYE PIECES

At Tufts College, a study of diopter settings of the eyepieces was made with a Navy Mark 2 Trainer. (555) Stereoscopic ranging was made on a stationary target. After preliminary instruction and trials on the instrument, 19 N.R.O.T.C. subjects were given ten trials of 20 stereo settings each of a stationary target. For five of the trials, the right and left eye pieces of the instrument were set at zero on the diopter scale by the experimenter; for the other five the subject set the eyepieces himself. Stereoscopic performance, for these untrained observers, was not found to be significantly different under these two conditions of diopter setting. During further trials the same subjects made 40 settings of the eyepieces and 30 stereo settings on a fixed target. Only the variability of the settings was found to be significantly correlated with either the average ($r = 0.70$) or the variability ($r = 0.57$) of the diopter settings. A reliability coefficient for diopter settings was found to be 0.81, showing consistency in the observers' capacity to set the oculars by himself. It will be noted that all of these subjects were untrained, that no statement of eye conditions is noted and that all are members of the N.R.O.T.C., which means that they were carefully selected for visual defects as well as for other factors.

A new method of obtaining eye focus on the height finder is reported by the Princeton Laboratory at Fort Monroe. (528) The method is based upon a series of judgments which the observer makes of the clarity or lack of clarity of the reticle pattern. The method consists of five steps. (1) The correct interpupillary distance is set into the eyepiece assembly. (2) The observer sets both eyepieces to 2 diopters.

(3) He observes binocularly the reticle pattern against a sky background. (4) This pattern is judged to be clear or not clear. If the former, the focus is used; if the latter, the setting for each eyepiece is reduced to +1.75 diopters, and the man views the field again. In resetting the eyepieces he takes his eyes from the instrument and sets each piece independently, making sure that the setting is accurate. (5) This procedure of resetting the eyepieces for successive observations is repeated, decreasing the setting by 0.25 diopter, until, for the first time, the observer sees the reticles as clear. The method is characterized as a binocular focusing method which establishes an equal eye focus for both eyes, and which determines this focus correct to the nearest quarter diopter.

A discussion follows as to why this method is preferred to the other two possible methods, namely, focusing each eyepiece separately and possibly to different amounts by bracketing to the clearest position for each eye, or rotating each eyepiece separately from maximum plus to the point where the reticle appears clear monocularly. Unnecessary minus in the setting is automatically compensated for by additional accommodation effort, making it impossible for the observer to tell that the minus is excessive and hence leading to eyestrain for continued observation. Convergence as well as accommodation is stimulated by excessive minus. For the 26 men in a Stereoscopic Observers' Class at Fort Monroe the correlation between the binocular focus data and refractions was compared with the correlation between the customary focus for right and left eye and monocular refractive data, and these were found to be very similar: +0.52 binocular; +0.52 used for right eye and +0.44 used for left eye. More important is the fact that the absolute values of the binocular settings correspond much more nearly to the absolute values of the refractive data than do the focus settings regularly used by the men. Three trials in immediate succession were made focusing by the binocular method. In only three cases out of 29 the difference between the greatest plus and the greatest minus focus exceeded 0.25 diopters. In two cases the range of these focuses was 0.50 diopter and in the other 0.75 diopter.

A study by Tufts College on the subject of diopter settings was made at the Advanced Fire Control School at the Washington Navy Yard. (574) This study was to determine the relationship of diopter settings of the eyepieces to subsequent scores of stereoscopic ranging on a stationary target on the Mark 2 Navy Trainer. An investigation was made with 82 trainees who had no previous experience with stereoscopic instruments. The ultimate purpose of the experiment was to determine whether the relationship is close enough to warrant using knowledge of diopter settings to select stereoscopic range finder operators. Diopter setting scores were correlated with average and variability scores of stereoscopic performance. The correlation coefficients computed were low (0.008 to 0.303) and may be regarded as significantly greater than zero only in the instance comparing variability of stereo performance and the difference between average diopter settings of the two eyes.

12.3 HEIGHT OF IMAGE ADJUSTMENT

A report from the Applied Psychology Panel, NDRC, dealing with height of image adjustment on the stereoscopic height finder, (74) records the results of several short experiments on the precision of height of image adjustments. It was found (1) that the average error of the height of image adjustment is about 0.5 mil of apparent field; (2) that the monocular and double image methods of adjustment are equally efficient for daytime observation; (3) that the precision of height of image adjustments does not change with the introduction of end window stops; (4) that height of image adjustment errors of 3 mils have a significant effect on the precision of RCS readings on stars but no effect on the precision of range readings taken in the daytime on ground targets. Finally, good observers are, in general, more skilled at making height of image adjustments than are poor stereoscopic observers. From these findings the following recommendations are made.

1. Both the monocular and binocular methods of making height of image adjustment should be taught all height finder and range finder operators.
2. Operators should make height of image adjustments with end window stops on the instrument when the instrument is to be used with stops for range or height readings.
3. Height finder and range finder operators should be given personal instruction on, and be required to record, height of image adjustment in order to improve precision in this adjustment.

A Brown University report in regard to the relation of the height of image adjustment error as found for different sorts of reticles will be found described in the section on reticle design. (179)

Two British reports deal with the problem of height of image error in stereoscopic range finders as reported by HMS Excellent. (304, 305) In the first report, experimental data show that when height of image error is present to the extent of about 10 minutes of arc of apparent field, an increase in mean consistency of the order of 60 per cent may be expected. The results also suggest that 3.5 minutes of arc is the amount of error which, in an M1 Stereoscopic Height Finder, just begins to affect performance.

Concurrently with this work, and presented in the second report, trials were made to determine the accuracy with which men can take out height of image adjustment error by the various available methods. The results indicate that men with average training could not take out this error accurately enough even by the monocular method. This was true even after they had had extensive practice. The investigators describe a new prism attachment, which in the future could be made an integral part of the range finder, by which the height of image error can be removed with great accuracy—to at least 0.05 to 0.25 mils or better.

Finally the report emphasizes the great importance of accurate adjustment of the stereoscopic range finders for height of image. This will necessitate very careful training at gunnery schools and constant practice at sea, and operators must make this adjustment with care on closing into combat. If the prism attachment referred to comes up to the high standard expected of it, and is incorporated in the range finder, it is anticipated the adjustment will be easily made and the training problem much simplified.

12.4 THE HEIGHT FINDER AS A SPOTTING INSTRUMENT

A laboratory study was made at the Ohio State University to determine the speed and accuracy in spotting with this sort of stereoscopic instrument. (330) The apparatus and method used in the investigation are described in detail in this report. The results indicate that under laboratory conditions in which a target of high contrast and sharp borders is used, subjects have been found to render stereoscopic judgments of the position of the target relative to a reticle mark after a lapse of time ranging from 0.4 to 1.5 seconds following the onset of the exposure. When the target is seen to lie in the same plane as the reticle, a longer time is required on the average to make the judgment than when the target is seen at a perceptible distance in front of or behind the reticle. These data refer to the situation in which the subject is instructed to respond as quickly as he can. If the subject is instructed to delay his response until he feels certain that further prolongation of the exposure would not influence his accuracy, it is found that some subjects show only slightly longer reaction times than in the situation in which they react as quickly as possible, but on the other extreme, one subject was found to use about three times as much time before making judgment. Subjects who used a longer time to make a response under these circumstances also showed a marked improvement in accuracy and precision. One subject showed no such improvement even when required to delay the judgment for five seconds. He was the fastest and most highly trained of the subjects and the reactions of the rest are probably more typical of Service personnel. Hence stereoscopic observers who are assigned to the duty of spotting should be encouraged to prolong the observation of the cloud of smoke produced by the bursting shell for approximately three seconds before making a judgment, provided the rate of fire is such that a delay of this length can be tolerated. Reducing the contrast slightly increases the reaction time for the stereoscopic judgment as well as decreasing accuracy and precision. Decreasing target size also leads to an increase in reaction time.

PART III

THE HUMAN OPERATOR

It has long been known that there is a very small percentage of human beings who can operate a range finder, especially a stereoscopic instrument, with anything approaching maximal accuracy. Chapters 13 and 14 outline the attempts to provide the Services with the best possible operators by selection of those most apt to become efficient operators and by the subsequent training of those selected.

Chapter 13 reports the experimental work on selection. The instruments themselves set certain limitations, such as a maximal and minimal range of interocular settings, or height limitation of the operator for the Army instruments. Furthermore, good intelligence and good mechanical ability are required. But more important still is the requirement of excellent stereoscopic acuity. At the beginning of the present war, no satisfactory and adequate test of stereoscopic acuity existed which would measure this factor with sufficient accuracy to be used as a selection device. A considerable part of this chapter deals with the search for such a stereoscopic acuity test. Many devices were tried and finally the stereo-vertical test was found to give satisfactory results. The chapter also tells of the battery of selection tests for stereoscopic range finder operators which were adopted by both Services and the plans and experience of the administration of these selection procedures in the Services. Validation of this selection battery of tests indicates that they adequately skim off the approximately best 3 per cent of the Service population who would be most benefited by subsequent training and who would become the most adequate range finder operators.

It was early recognized that the efficiency of a battery must depend on the continued accuracy of the range finder operator under the stress of combat. Hence some tests for a rough determination of emotional stability seemed desirable. The development of a group personnel questionnaire and of its validation is outlined in this chapter. It was never adopted for selection of range finder operators by either Service although it is widely employed in certain branches of the Navy and the Army where emotional stability is required by certain men in key positions or in performing especially hazardous tasks.

Chapter 14 deals with the training of the range finder operators so selected. It outlines measures of accuracy of performance and methods for measuring such accuracies. Learning curves, training methods and training devices are discussed. In this connection the Eastman Trainer was developed and experiments showed that preliminary training could be carried on as adequately with this training device as with the actual range finders and real targets. Thus many more trained operators could be made ready for combat at a time when the number of range and height finders available for training purposes was limited and aerial missions difficult to obtain.

Chapter 13

SELECTION OF RANGE FINDER OPERATORS

13.1 THE BATTERY OF SELECTION TESTS AND THEIR VALIDATION

One of the first problems attacked by the Princeton Laboratory at Fort Monroe was an attempt to analyze the special human competencies and abilities which would make an individual a good range finder observer. If this could be accomplished, it would then be simple to set up a series of tests for the selection of such operators. Previous to this time both the Army and Navy selected range finder operators largely by employing preliminary training as a screening procedure, so far as the determination of stereoscopic acuities were concerned. Obviously such a method was too slow and too cumbersome to be used in war time and with a very rapidly expanding Service personnel.

The Princeton Laboratory staff contained ophthalmologists, psychologists, and psychophysiologists who tested the Height Finder School personnel with a large number of tests, each of which seemed to have high face validity, in an effort to determine which of these might have the requisite internal consistency and which might actually validate against the School scores.

The Princeton Laboratory and several other groups tried a number of tests, all of which had a certain amount of face validity, to discover procedures which might aid in the selection of such personnel. The selection of stereoscopic range finder observers was a new problem and hence any test was tried which indicated a reasonable amount of face validity. Many of these tests proved of value and were adopted by the Services. For these particular scores or screening limits had to be set on the basis of experimental experience. Many of the procedures proved of no value and were dropped. Both adopted and rejected procedures are given later in this section.

Very early in 1942, just after Pearl Harbor, the Service Liaison Officers to the Princeton Laboratory project strongly urged that Section D-2 recommend a selection battery of tests for range finder operators. It was pointed out that the recommendation of such a battery in the then present state of knowledge could be little more than an informed guess, inasmuch as proper validation on a sufficient number of cases had not been made up to that time. However, because the urgency of the situation was evident, Section D-2 made tentative suggestion of such a battery of selection tests. (4)

13.1.1 Minimum Standards

This report suggests *minimum* standards as follows:

1. *General Intelligence:* A score of at least 100 on Army General classification 1A or at least 85 on Navy O'Rourke General Classification Test.
2. *Height:* Not less than 5 feet 6 inches. (This requirement could be disregarded for Navy personnel due to difference in equipment. It is necessary in the Army to permit the operator to look into the oculars when ranging near the horizon.)
3. *Mechanical Comprehension:* A grade of I, II, or III on Part 3 of Army test MA2 or MA3, or at least 75 on Navy O'Rourke Mechanical Comprehension Test.
4. *Vision:* Visual acuity of at least 20/20 in each eye
   Hyperphoria not greater than ½ prism diopter
   Exophoria not greater than 6 prism diopters
   Esophoria not greater than 6 prism diopters
5. *Interpupillary Distance:* Not less than 60 nor greater than 70 millimeters. (The interpupillary scale on the instruments actually runs from 58 to 72 mm but measurement of this distance was so frequently unreliable that the narrower distance was recommended.)
6. *Desire for Training:* After the nature and importance of the duties have been explained, select only those who answer "Yes" to the question, "Do you wish to be trained as a stereoscopic observer?" (This qualification was added to improve the motivation of the group of trainees.)
7. *Projection Eikonometer:* A grade of I or II (This is a test of stereoscopic acuity developed for the project.)

8. *Modified M2 Trainer:* A grade of I or II on the Stereoscopic Trainer M2, modified to include power-driven change in range.

It should be pointed out that the Eikonometer and M2 Trainer tests are the only two new tests over and above those already administered as routine in the Services.

These recommendations were promptly adopted by the Army and put into effect as soon as possible, initially under the supervision of the staff of the Princeton Laboratory. A description of these and other rejected tests will be found later in this section.

This first report was followed less than 3 months later by another which recommended the instruments to be employed in such an examination. (10) (covering 354). This report emphasized the two new instruments, namely, the Eikonometer and the modified M2 Trainer.

13.1.2 Screening Experience

A few weeks later this was followed by a report (11) (covering 355) giving a detailed manual for the administration of these tests. Some six weeks later and on the basis of a background of practical experience in the administration of these tests, a supplemental manual was recommended. (25) (covering 356). The changes were made on the basis of validation on the classes of stereoscopic observers at Fort Monroe and on the testing of large numbers of recruits at Fort Eustis and Camp Wallace. This report outlines the organization of a testing center. The results of experience indicate that only 3 per cent of a normal Service population succeed in passing all of the screening tests. However 80 per cent can be eliminated on the basis of a study of the Service Qualification card or the basis of General Classification Test or Mechanical Aptitude Test scores or because of height or age. Visual tests eliminate a further 8 per cent which leaves only 12 per cent of the total population who need to be tested on the Eikonometer and M2 Trainer. Certain substitutions of testing material are also recommended: a revised visual acuity chart with the Luckish-Moss Illuminator and a new chart to test heterophoria. The adoption of the Modified Massachusetts Vision Test Kit is recommended. Detailed instructions for the form of the Eikonometer Test, which is called the Stereo-Vertical Test, are given. By means of the development of a multiple recording device, this report indicates that it was now possible to test six subjects simultaneously instead of the single examination previously necessary. Detailed instructions are given for the filling out of the record cards.

A report on the validation of the tests by the Princeton Laboratory on students at the Height Finder School at Fort Monroe is given extensive treatment. (357) Unfortunately for this work, the primary mission of the School which was to train the largest number of best height finder operators, was so urgent that it could not be modified. As a result the population available was far too homogeneous to form a basis for validation and also the numbers were too small. In addition, many of the men reporting to the School had had previous ranging experience and this resulted in the individuals starting with widely different degrees of previous experience. A total of 179 men in six classes form the basis of the study. Men of the first five classes were assigned to the School from active organizations on the recommendation of their battery commanders. The men of the last class were selected by the Princeton Field Laboratory staff at Fort Eustis. Many tests were given to these men and only the few already specified above gave promise. Others will be discussed later in this section. The performance criterion employed was the observer's UOE which, it is believed, was an incomplete measure of proficiency but which was the criterion employed by the School for graduation. Observers' UOE were taken on fixed target and aerial target performance and grades on theory and records were also available. Only 5 men failed in theory and records, while 15 failed to pass the criterion of UOE on fixed targets, and 34 failed to pass the criterion of UOE for aerial targets.

The results form the basis for the recommendation of the Stereo-Vertical test rather than other possible tests with the Eikonometer. There was a positive correlation between mental ability and records and theory grade as well as a positive correlation between tests of mental ability and General Classification Test scores.

Standardization scores were obtained from testing from 223 to 291 men of the 5th Training Battalion at Fort Eustis who had an Army General Classification Test 1A score of over 90. In this way cutoff scores for Mechanical Comprehension, Eikonometer and the M2 Trainer were obtained. A revised battery of tests was given subsequently to 492 men at Camp

Eustis. Of these, 169 were given both the Eikonometer and M2 Trainer tests. Questions of operator differences were examined and standardized testing procedures were worked out.

At this point of development work on selection was turned over to the NRC Committee on Service Personnel—Selection and Training, which was subsequently absorbed into the NDRC Applied Psychology Panel. These groups retained much of the Princeton Laboratory personnel working on this problem and continued the validation of this screening procedure. Work was continued at the Height Finder School at Camp Davis. The net result of this work was the recommendation (73) to eliminate the M2 Trainer test because the Projection Eikonometer test alone gave more valid results and to lower slightly the passing score for the Eikonometer test. However, the substitution of the M2 Trainer test in place of the Eikonometer test is recommended for field or other situations where the Eikonometer is not available. These recommendations were subsequently adopted by the Navy for stereoscopic range finder operators. Results of the screening of 37,500 men at Fort Eustis during the year of June 1, 1942 to May 31, 1943 show that only 1,474 or slightly over 4 per cent of the population were accepted.

The validation of the tests as given in this report is based primarily on three classes at the Height Finder School at Camp Davis. These men met all the qualifications noted above except that a certain proportion failed to meet the scores for the M2 Trainer and the Eikonometer, but the group was representative of a random sample of the Army population in this respect. Previously the urgent need for trained stereoscopic observers of the highest possible quality made such a procedure impossible. Besides the Stereo-Vertical test with the Eikonometer and the M2 Trainer test, the Vectograph Pursuit and the Dearborn-Johnston tests were given these candidates. For criteria the following five measures of performance on the height finder were used as validation: (1) variability score in UOE; (2) course error score in UOE; (3) the "hit" score in per cent; (4) percentage of "good courses" score and (5) the sum of the course error and the variability scores in UOE. Criteria 1, 2 and 5 are "error" scores while 3 and 4 are "hit" scores. The variability score at a passing grade of 6 UOE and below had been used as the conventional measure of performance then in use for graduation at the Height Finder School. The new cutoff scores for the test of stereopsis are realistically based upon a consideration of a balance between obtaining a sufficient number of men for training, on the one hand, and of instruction cost, on the other. The Dearborn-Johnston test was not found satisfactory for purposes of selection. The Vectograph Pursuit Test might be considered advantageously as an alternative to the Projection Eikonometer test but was not recommended because of the need for further development and because of procurement problems. The results also indicate that some of the single tests did about as well as combinations of stereoscopic tests in terms of both selection and instruction costs. Therefore, the Stereo-Vertical test was recommended above because the Eikonometer in a satisfactorily developed form was available at testing centers with the modified M2 Trainer as a stand-by testing instrument.

On June 1, 1942 an actual testing center was set up at Fort Eustis staffed by Princeton Laboratory and by Service personnel. This field laboratory had a dual purpose: (1) to aid the Army in selection of stereoscopic operator trainees, and (2) to train Army personnel in the selection techniques employed so that aid from the Princeton Laboratory would no longer be required. Subsequently a similar testing center was set up at Camp Wallace on September 1, 1942, with the assistance of the Princeton Laboratory. The results of the testing in these two centers are recorded in a number of reports. (370) These form the basis of knowledge of selection costs from an unselected Service sample. These reports also contain a great deal of information regarding modification and standardization of the several tests in the battery necessitated by the shift from laboratory to field conditions. There will also be found a day-to-day diary which is of some general interest as indicating the difficulties attendant on setting up such a new project in a Service organization, in spite of the splendid cooperation given by the Army.

In these reports will be found the selection costs for each sub-test in the battery. A single sample indicates the selection costs. The results are those of the men tested between June 10 and June 30, 1942. Approximately 4,500 Army records were studied and, after elimination because of GCT and MA test scores, height, or indication that the men did not want training as stereoscopic observers, 687 men were selected for examination at the Stereoscopic Testing Center. The table on the following page indicates

the number selected and the causes of elimination.

Total number of men tested	687	
Passed and recommended	64	
Failed Vision Tests	245	
Interpupillary distance		36
Visual acuity		194
Heterophoria		15
Failed Performance Tests	378	
Did not see "stereo"		51
Projection Eikonometer only		69
M2 Trainer only		57
Both		201

From these figures it can readily be seen that visual acuity and the Eikonometer and/or M2 Trainer tests eliminated the largest number of men. The results clearly show the need for some special test of stereoscopic acuity, inasmuch as 378 of the men tested failed on these tests after they had successfully passed the general vision tests. Hence the belief that "good round eyes" are all that are needed to make a successful stereoscopic range finder operator was exploded.

Studies were made of the relationship of the several tests, such as the Eikonometer and M2 Trainer. On the basis of such experience, standard scores were developed for these tests and five grades were established. A study was also made of the distribution of scores by examiners. Certain examiner differences were evident and therefore much greater emphasis was placed on administration of the tests in standard form.

Time studies were made which indicated that the average examining time per subject for the visual tests was 7¾ minutes. The Eikonometer test required 29.5 minutes and the M2 Trainer test required 29.4 minutes. It should be noted that both of these tests required individual examination at this stage of development.

A second report covering July 1-15, 1942 indicates that 32 men were tested daily with little variation. This report contains a table of organization and description of duties of the testing personnel. The staff of a single unit calls for 2 officers and 18 enlisted men. Plans for suitable buildings to house such a testing unit are given. Such an establishment should operate at the rate of testing approximately 2,000 men per month. Detailed plans for testing booths and computing and administrative sections are given. There will also be found detailed descriptions of the necessary equipment for such a testing center. Finally, a course of instruction for examiner candidates, covering a 3-week period, is outlined.

The third report covers the period July 16-31, 1942. By this time the routine testing, computing, and administration of the Fort Eustis center was so well organized that attention was turned to training the additional examiners necessary to fill the cadres for Camp Wallace and Camp Callan, the other two Antiaircraft Replacement Centers. A study was made of the relationship between the performance of 1,053 subjects on the Eikonometer and the M2 Trainer tests. The coefficient of correlation is 0.21, which is not significant.

In a fourth report, covering the period August 1-15, 1942, a comparison is made of the scores given by regular examiners and by student examiners. These show very similar distributions for the Eikonometer test. For the M2 Trainer test the student examiners gave statistically significantly lower scores.

The fifth Eustis report covers the period August 16-31, 1942. In this will be found the plan and results of a test-retest program to determine the reliability of the testing procedures in use, both vision and performance tests. The plan called for retest by the same examiner in half the cases and by a different examiner in the other half. The results indicate a reasonable reliability for the interocular distance measurements (91 per cent within ± 1.0 mm).

For visual acuity only those who had passed were retested and results of the retest indicate that 97 per cent remained in the "passing" category. Similar reliability was found for the tests for phoria with none of the men who previously passed eliminated by the retest. For the performance tests, it was arranged that half of the men be tested first with the Eikonometer and the other half with the M2 Trainer. The results indicate that it makes no difference which test is given first. Similar test-retest distributions were found for the Eikonometer. There were, however, marked differences between distributions of the scores on the test and the retest on the M2 Trainer for all examiners. The results show considerable improvement in the scores obtained on the retest with this instrument.

A statistical study of these results indicates that the reliability of this test as then administered is only fair, the reliability coefficient being 0.74. The reliability coefficient is improved to 0.81 when the same examiner makes both tests. For the M2 Trainer test the reliability was not good, being 0.60 or only 20

per cent better than chance. Furthermore the reliability coefficient was not increased when both tests were made by the same examiner. A new method of scoring both performance tests failed to change the reliability coefficients to any considerable degree.

One highly significant development detailed in this report is the development of a Multiple Projection Eikonometer. By means of this instrument, it is possible to test six men simultaneously instead of the individual examination required for the former instrument. This development is of importance when it is remembered that the former instrument required approximately 25 minutes of examiner time for each subject tested. A manual for the operation of this instrument is included as an appendix to the report, with detailed instructions for the testing procedure and for computing and scoring the results.

The sixth Eustis report covers the period of the month of October 1942. This report contains a revised 3-week training program for examiners, consisting of lectures, classes, seminars, examinations and practical testing experience. Outlines of the ten lectures and of the final examination are given.

The seventh report outlines the revised organization of a unit consisting of 2 officers and 18 enlisted men who should each month be able to screen 3,500 records, give preliminary examinations to 1,500 men and administer complete stereoscopic tests to 1,000 men. Tables of organization and detailed duties of each of the personnel are outlined. Examination, computation, and clerical procedures are indicated. As illustrative material, a full report is given of the screening and examination of a typical battery (Battery A, 6th Battalion at Fort Eustis).

The eighth report covers the period of the month of September 1942. During this period 956 men were tested. They were selected from an initial screening of 4,832 records. Of these, 155 or 16 per cent of those tested passed all tests. It should again be pointed out that only slightly more than 3 per cent of the men whose records were screened passed all of the tests and could be recommended for training as a stereoscopic observer. Work was continued with a comparison of the Eikonometer and the M2 Trainer as testing instruments.

The ninth report covers the period of the month of October 1942. This report indicates that the Multiple Projection Eikonometer was now in use as a testing instrument.

During all of this time, the testing unit was charged with the selection of candidates for the Height Finder School at Fort Monroe. These records are full of the sort of incidents of apparatus failure and their correction which are bound to be encountered in any Field Testing Center.

A final report in this series tells of the establishment of a second Stereoscopic Testing Center at Camp Wallace and covers the period October 22-31, 1942. During the first month 1,622 records were screened; 40 were tested and of these 35 were recommended for stereoscopic observer training.

Late in 1942 the Committee on Service Personnel—Selection and Training of the National Research Council was formed. Inasmuch as work in the field of selection of stereoscopic range finder observers fell so completely within the province of the Committee, all work of this sort was turned over to them for further development and administration.

A report from HMS Excellent summarizes the British experience with selection tests for stereoscopic range takers. (301) The report sets up the following standards for selection with indication of validation experiments. (1) Interpupillary distance between 60 and 70 mm inclusive. (2) Ophthalmic standards: (a) visual acuity, each eye separately, 6/6, (b) refractive errors; total hypermetropia under homatropine and cocaine, +2.0 diopters of which not more than 0.5 diopter may be due to astigmatism; esophoria, 4 prism diopters; exophoria, 3 prism diopters; vertical phoria 1 prism diopter. (3) A standard score of 150 on the SA16 (75 per cent must be 17.75 mm or less). (4) In cases where the SA16 is not available men may be accepted for stereoscopic range finder training if they obtain a standard score of 100 on the M2 Trainer. The SA16 is a complicated form of a rod test presumably developed from the Howard-Dolman Test, in which the stereoscopic position of 4 rods is compared with a standard rod, which in turn may be set at varying distances from the observer. Instructions and standard scores for the SA16 and the M2 Trainer tests are included. It is concluded that the selection tests, here outlined, proved a satisfactory solution to the problem of selection but it was hoped that a new selection instrument then being designed might produce even better results.

The Applied Psychology Panel has prepared a manual for use in the selection of fire controlmen (0) in the Navy who are to be trained as stereoscopic range finder operators. (99) It concludes the direc-

tions for the organization, equipment, and procedure of a testing unit in a Naval Training Center or Naval Receiving Ship. It also includes detailed instructions for the administration of the various tests and for the reporting of the results. No tests not elsewhere described are introduced. The manual calls for an initial screening on the basis of certain qualifications on the General Classification, Reading, and Mechanical Aptitude tests with an age ceiling of 30 years. Only those men who meet all of these qualifications are sent to the Vision Testing Center. Here, for selection and classification as stereoscopic fire controlmen they must pass three more tests: with the Ortho-Rater for visual acuity, heterophoria, stereopsis, and color perception; with the OSRD Interpupillometer for measurement of interpupillary distance; and with the Multiple Projection Eikonometer for stereoscopic acuity. Approximately 90 men can be tested each day by a single Visual Testing Unit.

The following sections outline the developments of selection procedures, both those adopted and those rejected.

13.2 GENERAL FACTORS

Tests at the Princeton Laboratory (478, 481) indicated no relationship between range finder performance and age, weight, height (except that short stature may interfere with the operation of the Army antiaircraft instrument when ranging near the horizon), religious interest, or rural and urban birth and residence.

A number of psychomotor tests were also given. (474, 481) These included the two-hand co-ordination test, a reaction co-ordination test, a pursuit meter test, a dotting test, and a test of work decrement. No significant correlation was found for any of these tests and range finder performance as measured by the operators Σ log UOE score. With a steadiness test, (477, 481) there was a suggestion that men making a poor score on the test may be poorer range finder operators. The data did not give sufficient promise for further investigation. A study of pulse rate, blood pressure, and metabolic rate indicated little or no relationship with ranging performance. (477) There was slight indication that poor performance might be associated with high pulse rate and either high or low blood pressure. However, the preliminary results on a few subjects did not give sufficient promise for further development.

Tests of mental ability, spatial relations, and mechanical comprehension were also given to four classes at Fort Monroe. (479, 481) No significant correlations were found between any of these tests and range finder performance. The possible exception to this general statement was the suggestion that the mechanical comprehension test might have value as a part of a test battery, although it had little predictive value when given alone.

Besides the psychophysical tests and general background indicated in the paragraph above, a number of pencil and paper tests were given to the Fort Monroe trainees. (481) These were the Wunderlich-Hovland Personnel Test for mental ability; the Likert-Quasha Minnesota Paper Form Board for spatial relations and the Bennett Mechanical Comprehension Test. School attendance was also considered. No significant correlations were found again with any of these tests and ranging performance.

At Fort Monroe Height Finder School, some of the men who reported had had previous experience with the Army Antiaircraft Height Finder in amounts varying from 2 to 15 weeks, while others had had no previous experience whatsoever. A study of the men in two classes (504) indicates that the average performance of the men with previous experience is somewhat better than that of the novices. An arithmetic test, a specially devised dial reading test, and a test of aircraft identification were given to a group at Fort Eustis in January 1942. (502, 503) These tests were also given to one class at the Monroe Height Finder School and were found to have only a low correlation with School grades in both cases.

13.3 THE MEASUREMENT OF INTEROCULAR DISTANCE

The limits of interpupillary distance are determined by the limits for setting of the eyepieces on the instruments themselves. A study was made of the distribution of measured interocular distances of 6,554 white soldiers and 127 negro soldiers (145) at the Stereoscopic Testing Center at Fort Eustis. The distributions are given in both tabular and graphic form. The results indicate that less than 0.4 per cent of a total population will be excluded beyond the limits of 58-72 mm and less than 4 per cent beyond the limits of 60-70 mm. In actual practice in the screening of 37,500 men at Fort Eustis, only 500 men

were eliminated because they fell outside the range of 60-70 mm interpupillary distance. (73)

The early method of measurement consisted of the use of a millimeter scale held in front of the subject's eyes. This was known to be a relatively inaccurate method and the use of the Shuron Pupillometer was early recommended. This instrument is small and easy to obtain. The reliability of measurements by such an instrument was reported for test-retest data for 104 men and by four examiners. (486) Examiner differences were apparent. The probable error of measurement was slightly less than 0.5 mm. Of the 104 men measured, 62 measurements were the same in the retest while 9 were either 2 mm longer or shorter than the original reading.

It was pointed out (18) that serious range errors can occur unless the distance between the oculars of the range finder accurately corresponds to the interocular distance of the observer. At this time it was recommended that an accuracy requirement of 0.25 mm be placed upon the interocular adjustment mechanism. At the same time it was noted that no entirely satisfactory means for measuring the observer's interpupillary distance is now available. It was obvious that existing methods of measurement were not sufficiently accurate or reliable for this criterion.

Intensive research at Harvard University (282) following the suggestion from the Princeton Laboratory (522) indicated that the lines of sight in the telescopes of the range finders move with the oculars, whereas the observer's eyes do not. Hence, the binocular parallax between target and reticle may be changed solely by varying the separation between the eyepieces. This problem is discussed in full in Section IV B.

Study was made of the several existing instruments for measurements of this type. The Zeiss Gauge, and the Shuron Gauge were found to be unsatisfactory, primarily because of parallax introduced by IPD between the eyes of the subject and of the examiner.

This error can be eliminated by introducing a mirror with the Shuron instrument so that the subject makes his own measurements. Such a system was introduced in the Bausch & Lomb Gauge, which was also tried.

The Harvard group then developed an IPD gauge consisting of a mirror, two stadia wires, and a vernier attachment for changing the separation of the wires. The subject changed the separation until the wires and their mirrored images were coincident. Tests of five experienced observers, each of whom took five readings every day for 25 consecutive days, give average mean variation of the IPD measurement range from 0.07 mm to 0.11 mm. The mean variation of the averages varied from 0.03 mm to 0.11 mm.

During these experiments, however, the observers frequently reported parallax between the stadia wires and their reflected images. The reports were noteworthy because the parallax was perceived when the real wires appeared to bisect the observer's pupils. This state of affairs suggested that the observer's external lines of sight did not pierce the geometrical centers of their natural pupils. If this were true, it meant that IPD is an inaccurate measure of the distance separating corresponding lines of sight of the two eyes. Hence the Harvard group proceeded to measure the separation between the stadia wires when the parallax between each wire and its reflected image had been reduced to zero. Such measurements were called interaxial distance [IAD] and were found to have as high accuracy and reliability as had been found for IPD.

For the five skilled observers IAD and IPD were found to differ in amounts varying from 0.06 to 0.77 mm and in four of the five cases the IAD was larger than the IPD. Fourteen naive individuals were tested with the following results: in ten cases the IAD exceeded the IPD; in two cases it was smaller; and in two cases the differences were insignificant. Similar results were obtained with Service personnel in a Coast Artillery Battery and at Camp Davis. In both samples it was found that there was only a small percentage who had equal IPD and IAD and that in most cases the IAD measurement was greater than that of IPD.

An engineered model of the interaxialometer was constructed under Navy auspices and was tested with both trained observers and with Service personnel. It proved to be both accurate and reliable, with a very large percentage of the measurements having an average mean variation of not more than 0.15 mm. Considerable experimentation was done to determine the properties of IAD as affected by accommodated distance, ocular vergence, uncontrolled vergence, lateral eye movements, vertical rotary eye movements, and vertical rotary head movements.

A study with range finders was made at Bausch & Lomb (107) to determine if the IPD or the IAD should be set into the instruments. Readings were

taken on an indoor collimator with various separations of the eyepieces with expert observers whose IPD and IAD had been determined. Of the four observers, three turned out to have IAD narrower than IPD. For two observers the best results are obtained with the IPD set into the instrument, for one observer with the IAD measurement, and for the fourth observer with neither. Results from Camp Davis favored the use of the IPD although it was again demonstrated that considerable differences were apparent between the IPD and IAD of most of the men (150).

The results are somewhat confused. The Harvard group concluded that the oculars should be set at the interaxial when using large exit pupils and the interpupillary distance when using small ones (the latter because the danger of "clipping" is thereby minimized). It was evident, however, that when the exit pupils are very small (ca. 1 mm) the errors due to incorrect interocular setting are negligible. With large exit pupils the interocular setting is critical, and, in the case of some observers at least, equal to the interaxial separation.

Because it seemed inadvisable to have two forms of interocular measurement to be set into the instrument at different times and under different conditions and to emphasize the value of stopping down the range finder whenever possible (cf. section on perspective errors), it was recommended (66) that the IPD be adopted throughout and that the instruments be used in a stopped down condition whenever possible. It was also recommended that the IPD be measured by means of the Bausch & Lomb Duplex PD Gauge.

An instrument was developed at Camp Davis (147) which combined a Shuron Interpupillometer with a mirrored reflection. This instrument measures IPD. For 36 subjects the difference between the median value of two sets of three readings each was the same in 13 cases; varied by 0.25 mm in 15 cases; by 0.5 mm in 7 cases and by 0.75 mm in the remaining case. Test-retest reliability was high with no difference in 36 per cent of the cases; 0.25 mm difference in 42 per cent; 0.50 mm difference in 19 per cent and 0.75 mm difference in the remaining 3 per cent.

A comparative test of the reliability and precision of the NDRC and the Bausch and Lomb Interpupillometers was performed at Fort Lauderdale. (82) A total of 81 men were measured twice by each instrument to determine their interpupillary distance. This analysis shows that the range of measures of interpupillary distance obtained was comparable to that of a male Army population and also that there are no significant differences between the means and standard deviations of the measures obtained on the two instruments. However it was found that the dispersion of differences between test and retest is significantly less for the NDRC instrument than for the B & L Duplex P-D Gauge. A significantly greater proportion of measurements obtained with the NDRC instrument fall within the tolerable limits required for range finder operation (± 0.25 mm) than those obtained with the B & L instrument. It was also found that the coefficients of correlation for reliability of both instruments are very high but those for the NDRC instrument are significantly higher, and that the probable error of the B & L instrument is greater than the NDRC. On the basis of these findings, the use of the NDRC Interpupillometer was recommended to the Services. A description of the instrument and a manual for its use are included as an appendix to the report.

A complete description of the laboratory model of the NDRC Interpupillometer and its carrying case are outlined in a report (106). Suggestions for modification of this laboratory model for a field instrument are also given. The instrument consists of two eyepieces whose horizontal separation is controlled by adjustment screws. Bulbs below the eyepieces illuminate the pupils of the individual whose interpupillary distance is being measured. A mirror behind the eyepieces provides a reflection of the pupils and the hair line which is etched vertically in the glass of each eyepiece. A vernier millimeter scale which can be read from the rear of the instrument indicates the amount of separation of the hairlines. An adjustment is provided in the instrument and a method of calibration is recommended in this report which assures that the scale correctly indicates the separation of the two hairlines.

A new measure of interpupillary distance is reported by Brown University. (180) The technique involves the photographing of the two eyes simultaneously with an adapted form of graflex stereoscopic camera against a millimeter scale. The report gives the results of 37 subjects whose interpupillary distance was measured twice each day by this new device and the NDRC Interpupillometer with a week elapsing between the two sets of measurements. It was found that the distributions of IPD found by the two

methods were very similar. The reliabilities of the two methods, as judged by differences between test and retest of each subject, are not significantly different. With the stereo-camera method 25 observers showed a difference between test and retest of not more than 0.2 mm while 26 were within this tolerance with the NDRC Interpupillometer. It is pointed out that the interpupillometer technique is less cumbersome and better adapted to field use because it gives an immediate result and is not dependent upon the processing of film and the measuring of the photographic record. The camera method, however, possesses the advantages of being relatively objective and of providing a permanent record of the measurement.

13.4 VISUAL TESTS

Criteria of visual acuity and of determination of possible phorias were already part of the screening procedure for both Services when experimental work was begun on this problem. On the basis of such a background of experience and because the selection cost was not too high, these same criteria for selection were recommended. (4) Indeed, no considerable amount of experimentation was done on this phase of the selection problem.

Results of the 9,675 men left to be screened at Fort Eustis after elimination for Army General Classification Test and MA scores, height, age, and IPD indicate that 3,280 were rejected because they failed the visual acuity test of 20/20 vision and an additional 152 men were eliminated because they had a hyperphoria of more than 0.5 prism diopters or an exophoria or esophoria of more than 6 prism diopters. (73)

A careful refractive examination was made of the men of Class 11 at Fort Monroe. (505) Refractive errors and phorias were determined. Such errors proved to be of little consequence to the group as a whole, although certain errors were detected in some of the men. The school performance for UOE for both fixed and aerial courses for the seven men with demonstrable defects but within the limits of the selection criteria, did not vary to any considerable extent from the average of the remaining 22 men of the same class.

Ophthalmograph tests were made on three classes at Fort Monroe. (476) No statistically significant differences were found between UOE error and saccadic interval, fixation time, or degree of fixation tremor. An examination of the data for the second Eustis testing (485) showed no significant relationship between visual acuity and the focus used on the M2 Trainer. Of the 201 cases, 121 used zero diopter difference in focus between eyes and only 14 used a difference of more than 0.5 diopter. A study was made (493) of the relationship of visual acuity and scores on several tests of stereo acuity. From these results it is apparent that, within the visual acuity range of eligibility, there is little relation between visual and stereoscopic acuity. In many cases improved visual acuity does correspond to improved stereoscopic performance but the effect is of small magnitude. Again at Fort Monroe, using 9 men, an investigation of a possible relationship between "near" phoria measurements and fixed target consistency showed no indication that changes in phoria are connected with variability in fixed target readings. (506) This statement holds both for changes from day to day and for changes within a single day.

In a later study (76) the relationship between visual acuity and stereoscopic visual acuity was examined in order to see whether lowering of the present standard of visual acuity would result in an increase in the number of men passing the stereoscopic tests, thus increasing the pool of men eligible for training as stereoscopic height finder observers. One thousand and fifty-two soldiers were permitted to take the tests of stereoscopic vision at the Stereoscopic Testing Center at Fort Eustis even though they failed to meet the usual standard of visual acuity of at least 20/20 in each eye (unaided). Analysis of the results showed that although the elimination of the test for visual acuity would produce a slight increase in the number of men who qualify on the stereoscopic tests, the burden of such testing would be greatly increased because a large majority of men with vision poorer than 20/20 fail the stereoscopic tests. However, screening at any level of visual acuity is better than no screening at all, as the performance on the stereoscopic tests of the subjects with visual acuity of less than 20/20 standard vision is significantly poorer than those with standard vision. Hence the test of visual acuity serves as an effective and time-saving screening device for the stereoscopic tests. It does not in any sense replace the stereoscopic tests, since, of the men with 20/20 vision or better, only 12 per cent pass the stereoscopic tests. It was recommended that the criterion of 20/20 vision or better be re-

tained as a selection standard.

A study of the reliability of visual acuity testing by a test-retest study using a floor model Projectochart with an E slide was made on 389 cases at Fort Eustis. (487) The results show that there is a statistically significant but practically negligible improvement in average acuity on retest. Only 39 per cent of the men shifted by more than one class interval. Hence it was concluded that the reliability of visual acuity measurements was satisfactory for screening test purposes.

The Massachusetts Vision Test Kit and the Bausch and Lomb Ortho-Rater were used to test 288 soldiers at Fort Eustis to determine visual acuity. (84) The results indicate that these tests of visual acuity are satisfactory substitutes for each other and that either instrument can be used for the rough screening procedures which precede the careful testing of stereoscopic vision for selection of range finder operators.

13.4.1 Aniseikonia

Any ocular condition which would lead to an apparent distortion of spatial relations would obviously affect accuracy of ranging. Such a condition is found in aniseikonia, in which there are size differences in the images of the two eyes.

This was studied at the Princeton Laboratory at Fort Monroe. Indeed, the introduction of the Eikonometer as a testing instrument was for this purpose. Several cases with this defect were found in Class 8. (469) In order to detect aniseikonic subjects easily a leaf room was installed in the laboratory at Fort Monroe. Men in Height Finder School Classes 8-11 were tested. (499) Four degrees of aniseikonia from 0 to 3 are recorded. A statistical examination of the data showed no significant differences in performance on the height finder between degrees of aniseikonia. In another study of these data (508) it was found that the degree of defect was much smaller than the values obtained for an average college student population and is comparable to those found in a highly selected population of aviation cadets. This is true for size differences in both the horizontal and vertical meridian.

For the 71 cases at Fort Monroe, none had a size difference in the vertical meridian greater than 1 per cent. In the horizontal meridian there was one case with a size difference of the images of the two eyes of 2.5 per cent and there were two other cases with differences greater than 1 per cent. It was found again, when the sum of size differences with two meridians were added, that there was no relationship between degree of aniseikonia and the combined UOE scores for fixed and aerial targets. It is pointed out that the screening for visual acuities, the phorias, and a degree of stereoscopic acuity probably will catch all cases of aniseikonia serious enough to affect ranging accuracy.

13.5 THE SEARCH FOR A TEST OF STEREOSCOPIC ACUITY

13.5.1 Validation of Tests of Stereoscopic Vision

It became evident early in this work that a valid and reliable test of stereoscopic acuity was needed. At this time two tests were readily available. The Howard-Dolman peg test was a dynamic test used by the Air Force but with which they were dissatisfied. This test could be administered only individually and took a long time for each subject. There was also a single sheet of the Keystone Test which allegedly measured stereoscopic acuity. One glance at this card through a stereoscope immediately convinced a normal subject that it was far too easy as a selection device for as important a job as that of range finder operator. At Fort Monroe, in the Princeton Laboratory, two tests were developed early. The M2 Trainer was used as a testing device. This was in the nature of a job miniature. Further development introduced known dynamic courses in this instrument. The second device had to do with the development of the Eikonometer as a testing device for this purpose. These developments will be outlined in detail below.

However in the early stages of the Eikonometer development and until now for the M2 Trainer test, each subject had to be tested individually. This led to a very considerable testing load. Furthermore both tests required highly trained personnel for adequate administration. Hence the search continued for an adequate but simpler means of screening this human ability. It should be pointed out that both the M2 Trainer test and an earlier form of the Eikonometer test were recommended in February 1942 in the first selection battery. (4) The revised Eikonometer test and the M2 Trainer test as alternate remain in the most recent screening recommendation in August 1943. (73)

At the Harvard Psycho-Educational Clinic a study was made of the Howard-Dolman apparatus under standard conditions of various sorts. (289) It was found that illumination with lumiline light sources eliminated shadows but made a brightness discrimination between the two posts possible. Hence judgments could be monocularly employing a brightness criterion which had nothing to do with stereoscopic vision. The apparatus was extremely unreliable under all of the experimental conditions employed and it was recommended that it be dropped from consideration as a screening test. If it should be employed, illumination should be provided by a single 200-watt bulb above the apparatus. Such illumination does not yield any cues in the form of brightness changes on the movable post.

At Tufts College a research apparatus was developed which was called the Tufts Trainer. (557) This was a job miniature of the range finder and was developed as a research instrument for study of problems of ranging on either stationary or moving targets. It had the advantage of an easily identifiable and adjustable zero point. It was recommended as a possible training and selection instrument. Inasmuch as real depth was measured, this instrument had much greater sensitivity than an instrument which depends on decentration as was the case with the M2 Trainer. However, the instrument was large and cumbersome and it was not recommended for adoption. Nevertheless, it was adequate as a research instrument and the Tufts group validated a number of tests of stereoscopic vision by its use.

Several tests were used at Tufts: (1) The Bott Test of Stereopsis; (2) the Keystone Test (both of which are static tests); (3) the M2 Trainer test; and (4) readings on the Tufts Trainer. Data were gathered from 56 members of the local Naval ROTC who took the Bott Test of Stereopsis twice and made stationary and moving target runs with the Navy and Tufts Trainers. The results indicate that the Bott Test is fairly reliable and is considerably better than the test-retest reliability for either the M2 or Tufts Trainers probably because of the apparent learning factor for these two instruments.

In another experiment (566) 88 men and women were tested and retested with the Bott, Mark 2 and Tufts Trainer tests. The results showed certain variations in the two sex groups. The scores of the Bott Test showed the highest reliability coefficients of 0.76 for men and 0.83 for women. A study of intercorrelations was made between the Bott Test and the M2 Trainer and Tufts Trainer employing both fixed and moving targets on the two latter instruments. (565) It was found that the scores of the Bott test do not correlate with those of either of the other two instruments. Nor do the scores of the M2 and Tufts Trainers correlate with one another. However, correlations between stationary target and moving mean target scores made on the same instrument are quite high, indicating that an individual tends to maintain his constant error on the same direction and of about the same magnitude when the target in either of the instruments is moving as when it is stationary. Intercorrelations between standard deviation scores on the M2 and Tufts Trainers are significantly different from zero.

In still another experiment at Tufts College (568) a group of 60 college undergraduates, who did not wear glasses, took the Stereometric Section of the Keystone Diagnostic Series and the Bott Test of Stereo Acuity. It was found that the "number wrong" score and the "per cent stereopsis" score correlate highly on the Keystone Test, with a coefficient of 0.82. The "number wrong" Bott score correlates 0.69 with these Keystone scores. Analysis of the Keystone responses lead to the important finding that the threshold of stereopsis is proportional to the size of the test objects. Smaller decentrations are correctly perceived when the test objects are larger. Incorrect responses were predominantly for the largest test objects, almost to the exclusion of other incorrect stimuli. This criticism alone goes far toward invalidating this material for diagnostic test purposes. In another experiment intercorrelations were determined between results of a number of short tests administered to 50 Naval ROTC men and 32 unselected students. The tests given were the M2 Trainer, Tufts Trainer, Bott Test of Stereo Acuity, Vectographic Pursuit Apparatus, and the Wulfeck Group Test of Stereo Acuity. (569) The last two tests will be discussed later. It was found again that the Bott Test correlates poorly with the M2 and Tufts Trainer (0.20 and 0.30 respectively). Scores on the Vectographic Pursuit Apparatus correlates at the level of 0.50 with the two trainers. In another report (567) it was determined that there were no significant sex differences in the performance of 56 men and 32 women on the Bott, M2 Trainer, and Tufts Trainer tests. A memorandum from the Howe Laboratory gives the results of the Howard-Dolman and

Verhoeff Size-Confusion Tests on the student body of Andover Academy. It was found that the Verhoeff test had much higher reliability than the Howard-Dolman while the correlation between the score of the two tests was 0.44.

The general conclusion from all of these results was that static and dynamic tests of stereopsis measure different abilities in the human subject. Furthermore, it became evident that the ability measured by static tests did not correlate with ranging performance. This decision led to the abandonment of static tests and emphasized the development of dynamic tests for the measurement of stereoscopic ability as selection procedure for range finder operators. The test has the advantage of administration to as many subjects simultaneously as there are test materials available.

However, before this decision was reached, there had been developed the Wulfeck Group Test of Stereo Acuity at the Princeton Laboratory at Fort Monroe. This was another form of static test. It consisted of a series of vectographic pictures showing a simplified reticle with a small image of an aeroplane either in front or in back of the fiducial mark by known amounts. These had to be viewed through Polaroid glasses. It was developed because it seemed to have high face validity. The Wulfeck test was given at Fort Eustis (498) to 165 men for whom the M2 Trainer and Eikonometer scores were also available and to 473 men for whom there were General Classification and mental ability scores available. The test proved to be reliable, giving a test-retest correlation of 0.74. The distribution of scores was fairly normal, with something of a skewing toward the high scores. There was a wide distribution of scores from 3 to 40 which was maximum. There was, however, a negative correlation between Wulfeck scores and those of either of the two dynamic tests of stereoscopic ability. Small positive correlations were found between Wulfeck scores and scores on the Mechanical Ability Test and those on the General Classification Test. An item analysis was also made. Another report (370) outlines the results of the administration of the Wulfeck test to 291 men at Fort Eustis and Class 12 of the Height Finder School at Fort Monroe. It was found that Class 12 showed a higher mean and smaller standard deviation than the general population although the differences are not statistically significant. The correlation of the Wulfeck test with Class 12 performance was log UOE, aerial +0.25. It should be pointed out that the sign of these correlations is opposite to expectation and, taken at face value, they imply that poor stereoscopic acuity as measured by the test is associated with superior performance on the range finder. At the Harvard Psycho-Educational Clinic, 19 unselected subjects were tested with the Wulfeck Test and the Vectographic Pursuit Apparatus. The reliability of the Wulfeck Test was found to be 0.83 on a test-retest basis. The correlation between the static Wulfeck Test and the dynamic Vectograph test was only 0.17. (292)

From these results it became evident that the Wulfeck Group Test of Stereo Acuity was not an adequate screening device for the selection of range finder operators where only the very best were adequate for such training. About this time the Army and Navy Aviation groups requested that the test be given to pilot candidates to determine if this test would be an adequate substitute for the Howard-Dolman test then in use. If such a substitution could be made it would obviously save a very great deal of time in testing administrative personnel.

A group of 235 men already accepted for pilot training were tested at Randolph Field with the Wulfeck Test, the Howard-Dolman Test and the Keystone Test of Stereo Acuity. (580) The last two tests were administered by School of Aviation Medicine personnel. Later, at Kelly Field, 310 men were tested who were aviation candidates but who were not accepted as pilot candidates. These men were given the Howard-Dolman and the Wulfeck Tests only. The Keystone Test proved to be so easy as to be not diagnostic at Randolph Field and hence was eliminated from the Kelly Field testing. A total of 204 of the 235 men obtained an absolutely correct score on the Keystone Test.

In regard to the Howard-Dolman test it was found that the illumination varied at the two fields, by tubular fluorescent lamps at Randolph Field and by a single electric bulb at Kelly Field. This was a retest for the men at Randoph Field because they must have already passed the Howard-Dolman Test to have been accepted as pilot candidates. It turned out that 31 cases or 13.2 per cent failed to obtain the passing grade on this retest. These men were brought back for an additional retesting and 29 of the 31 succeeded in getting a better score than they had before, and only 11 still failed to meet the Howard-Dolman cutoff score of 30 mm. This gives evidence of the low reliability of the Howard-

Dolman as a screening test.

An analysis of the frequencies with which the different digits appear as the last digit of the Howard-Dolman scores indicates a predilection for round numbers on the part of the examiners for both the Randolph and Kelly Field data.

The distribution of scores of the Wulfeck test are similar to those obtained at Fort Eustis with a skewing toward the good scores. The position of the curves on the abscissa are similar for the two sets of data for the selected aviation candidates and are significantly moved toward the better scores as compared with the Eustis data. The means are: Eustis—26.33; Randolph Field—32.88 and Kelly Field—32.03. Little relationship was found between Wulfeck and Howard-Dolman scores.

A similar testing with the Wulfeck Test was made at the Philadelphia Navy Yard (583) of 165 aviation candidates in eight classes. Results are essentially similar to those obtained at Randolph and Kelly Fields. All of these findings are summarized in an additional report. (581) It had been hoped that flying data would be forthcoming in order to validate the tests for the purpose of screening pilot candidates. This proved impossible for the men tested at Randolph and Kelly Fields because of the difficulties of following the men from one field to another during their training. At the Philadelphia Navy Yard the Flight Jackets were available for study during the candidates' preliminary flying training. However, the Navy system of scoring candidates made such a validation impossible and the attempt was discontinued (582, 584).

There is no doubt that Wulfeck Test measures something because of the high degree of similarity of score distribution from the several samples and because of the reliability of the test itself. The three highly selected aviation samples possess more of this ability than the relatively unselected Eustis samples. However, validation with range finder performance was negative and with flying performance was lacking. The Wulfeck Test proved useful in several instances subsequently for the elimination of individuals who had little or no stereoscopic competency. One suspects that it will do a better job than the Keystone Test. This work again emphasized the fact that static tests of stereoscopic acuity are inadequate for screening individuals who are to be faced with a dynamic stereoscopic job.

The Psycho-Educational Clinic was given the task of developing such a dynamic stereoscopic test. The M2 Trainer and the Eikonometer Tests (to be discussed later) were already in existence and were being used for selection. However, at this stage of development, both required examination of the individual subject for an average time of one-half hour. This was an enormous expenditure of examiner time and hence some sort of dynamic group test of stereoscopic acuity was desired. Using the vectographic technique, the Harvard Psycho-Educational Clinic developed successively several instruments which were subsequently tested for reliability and validity.

The Vectograph Pursuit Apparatus is an instrument in which the individual subject was asked to keep contact between a reticle and a target apparently being moved in depth by cam action. Contact is maintained by turning a wheel which changes the degree of disparities of the two target images and hence changes the apparent depth of the target when seen through Polaroid spectacles which allows each image only to reach either eye. This is described and its operation discussed in detail. (301) Ten members of trained height finder crews of the 36th AA Brigade were ranked for efficiency in actual ranging by the senior sergeant. The scores of these subjects on the Vectograph Apparatus ranged from 49.3 to 42.4. The four highest scores account for four of the five men selected by the sergeant as his best observers. (284, 290) Four men of a height finder crew of each of two other batteries obtained Vectograph Pursuit Apparatus scores in exactly the rank order of efficiency as rated by the Battery Commander. The lowest score of these eight men was 42.8.

Contrasted with these, 20 untrained men were given the same test. The scores ranged from 47.3 to 20.9. Only three men of this untrained group exceeded the worst score of the men of the trained group, one other man getting a similar score. Translated into UOE the mean score of the trained operators was 3.0 UOE while that of the untrained group was 20.0 UOE. Reliability of the instrument was high (0.82) as determined by the test-retest method on 47 high school students.

The Vectograph Pursuit Apparatus was standardized on a highly heterogeneous group of high school and college students and of soldiers. By this means a set of decile standard scores was evolved. (284) The distribution curve is very heavily skewed toward the higher scores. It should be pointed out that it is in this region of higher scores that differentiation is

desired if one is to skim the cream in the selection of range finder observers. And it is just here that good differentiation is lacking.

In the same paper the effects of learning with the Vectograph Pursuit Apparatus are discussed. Twenty-six subjects were given five successive trials. The learning factor is not great and is practically negligible for those subjects who get good scores.

Another experiment employed 44 subjects in (284) a comparison of dynamic courses and judgments of static settings with this apparatus. Eight of the ten subjects who performed best on the static test were in the top 30 per cent of the dynamic operators, while only four of the ten best dynamic operators were included in the 10 best static subjects.

The phorias of 46 high school and college students were also tested. The eight subjects with measurable phorias all did very poorly on the apparatus. (291) The relation of ocular dominance and Pursuit Apparatus performance was studied on 29 subjects. The results indicate that subjects do better if one or the other of the vectographs is held constant. Subjects tend to obtain low scores when obliged to fixate the stationary vectograph with their non-dominant eyes.

There is no correlation between Vectograph Pursuit Apparatus score and intelligence, and only a slight correlation with the Bott Test (0.35). Somewhat larger correlation coefficients were obtained with Vectograph test scores on the one hand and Tufts Trainer (0.50) and M2 Trainer scores (0.64) on the other. (287)

In a further effort to validate the Pursuit Apparatus, an experiment was carried on with a heterogeneous group of 67 soldiers of the 68th AA Brigade. Each man took five readings on a fixed target at over 5,000 yards. Very great variation was found between subjects and in the same subject from trial to trial. Correlations between early or widely separated trials was very low. These correlations were higher for third and fourth (0.58) and fourth and fifth (0.48) trials. It is concluded that the range among subjects in regard to stereoscopic ability is very large, running from little or no ability to extremely fine discrimination.

The members of a Height Finder Class were tested at Camp Davis with the Vectograph Pursuit Apparatus. (288) They were a highly selected group trained in the use of the ranging instrument also. A total of 36 men were tested. Of these, 25 obtained a score of better than 48 and only two had a score of less than 46. Two of the three men obtaining the worst scores were better on the Pursuit Test than the poorest of the trained height finder operators previously tested in the Boston area.

At this point of development, this project was turned over to the Committee on Service Personnel—Selection and Training, of the NRC, who were concerned with the further development.

The Vectograph Pursuit Apparatus was adapted to test 12 men simultaneously. (284) This was accomplished by providing each subject with a push button by means of which he could record his judgments of the time the target crossed the fiducial plane of the reticle.

The Vectographic Pursuit Apparatus was improved by placing the target plates in a better position and installing an apparatus so that integrated scores could be read off immediately at the end of each trial and by improved recording apparatus.

A variation of this apparatus is described as the Dearborn-Johnston Test for Depth Perception. (285) In this test a target seems to be moving back and forth across a fixed reticle. The subject has merely to count and record the number of times the target crosses the fiducial plane. The extent and number of the oscillations varies for each of three courses. Details of construction and of operation are given. The distribution of scores is heavily skewed toward the lower scores. Experience shows that nine subjects can be tested in 12 minutes. The reliability of the test is 0.82.

For the final validation, arrangements were made to admit to the Height Finder School at Camp Davis a certain proportion of men who did not meet the current standards for selection. Three classes were admitted who passed all other requirements except for stereoscopic acuity but these were selected so that their scores on the M2 Trainer and Eikonometer Tests were representative of a random sample of the Army population. This procedure guaranteed a suitable spread of ability on those two instruments and probably an associated spread on the Vectograph Pursuit Apparatus and the Dearborn-Johnston tests which were being tried as supplementary stereoscopic devices.

Reliabilities in this experiment for both tests were lower than had been found previously. By the test-retest method the reliability coefficient for the Vectograph Pursuit Apparatus was 0.75, slightly higher than that for the M2 Trainer but lower than that

for the Projection Eikonometer. The reliability coefficient for the Dearborn-Johnston Test was 0.67, the lowest of all four tests of stereopsis used. (295) The scores of the Vectograph Pursuit Test correlated 0.32 with the Eikonometer and 0.41 with the M2 Trainer test. The Dearborn-Johnston Test correlated 0.21 with Eikonometer, 0.16 with the M2 Trainer, and 0.44 with the Pursuit Test. (293) Practice effects with the Dearborn-Johnston test are discussed. (296)

Validation of those tests were made against the last 22 aerial courses when true target positions were obtained by the phototheodolite records. The following measures were obtained: the variability scores in UOE; the course error score in UOE; the "hit" score in per cent; the percentage of "good courses" score; and the sum of the course error and variability scores in UOE. (73)

The variability score is a measure of the variation in the readings taken by the height finder operator. For the 22 courses this score is the median spread of the spread of readings of the individual courses in UOE. The course error score in UOE is an accuracy score and is the median deviation in UOE from true range (as determined by the phototheodolite records) for all of the 22 courses.

The "hit" score in per cent is obtained by dividing each individual course of the 22 courses into five parts. Medians of those parts of an individual course which fall within the limits of 1 UOE behind true target position and 2 UOE in front of true target position are considered to be "hits". For each course, the "hit" score is those parts which fall within the specified limits as a percentage of the total number of parts of the course. The criterion "hit" score is the median of the 22 percentages obtained for the last 22 courses of the examination.

The percentage of "good courses" score is obtained by assuming that those courses which show (a) a performance variability of 4 UOE or less and (b) a course error of 2 UOE or less are "good courses". Such "good courses" are treated as a percentage of the total number of courses. This score emphasizes data falling within limits which assure a minimum of director instability. The "good courses" score, therefore, emphasizes the nature of data which are good in terms of director function.

Finally, the sum of the course error and the variability scores in UOE considers that the median score for each component variable is indicative of that variable's contribution to the error variance. This score was also developed in terms of the type of data which the director can use most efficiently.

Test-retest reliability coefficients of these five performance criteria are, in rank order: sum of variability and course error—0.87; variability—0.82; course error—0.68; per cent of good courses—0.67 and "Hits"—0.58. (73) Intercorrelations are high (7 of the 10 over 0.80) either positive or negative as must be the case when some of the criteria record errors and others record hits. On the basis of this analysis of criteria only two were considered on the final validation—variability score with a cutoff at 6 UOE and the sum of the variability and course error with a cutoff at 9 UOE. The first of these is the conventional measure of performance used for graduation at the Height Finder School. The second was used as a criterion because, theoretically, this score defines a man's performance in terms which may be related to the probability of his success as an integral part of a successful antiaircraft unit. These two criteria correlate very highly with one another, the coefficient of correlation for these data being 0.97.

The results indicate that there is a relationship between Vectograph-Pursuit and Dearborn-Johnston scores which is better than chance at the 1 per cent level. The Dearborn-Johnston scores are just above this level while those for the Pursuit test are better. In neither case are the validations as good as either the M2 Trainer or Eikonometer scores. (297, 298)

A description of the Dearborn-Johnston Test of Stereoscopic Vision (297) and a description of the standard administration of the Vectographic Pursuit Test (299) have been carefully worked out.

As a result of this validation the final recommendation for the selection of range finder operators in August, 1943 dropped the Dearborn-Johnston Test from consideration entirely. Recommendation is made that the Vectograph Pursuit Test might be considered advantageously as an alternative to the Projection Eikonometer Test. But its use was not recommended at that time because of developmental and procurement problems.

13.5.2 The M2 Trainer Test

Early in the work at Fort Monroe it was found that the M2 Trainer was too easy for training pur-

poses when used in the conventional way of making static settings. Manual control of range change was not feasible because such changes, introduced manually, were not sufficiently slow or smooth and not sufficiently uniform from test to test. Hence the Princeton Laboratory devised a modification of the M2 Stereoscopic Trainer by introducing power control of range change. This was accomplished by coupling a range drive unit to the trainer by looping a rubber belt on the auxiliary range knob to connect with a pulley on the motor shaft. (509) With this modification it was possible to repeat exactly the same course over and over again or to change the course by the simple expedient of changing a cam.

With this possibility of having the M2 Trainer a dynamic instrument with a standardized course, it was early used as a selection device for testing stereoscopic acuity. Here was a ready-to-hand job miniature for use for this purpose. A manual for such testing was subsequently written. (151) A new form of motor drive was described in a subsequent document (155) which had certain advantages over the earlier modification of the M2 Trainer. This enables the progressive change in the stereoscopic position of reticle pattern and target to vary at different rates; it presents both an approaching and withdrawing course and permits a selection of drive rates. Variation from 20 UOE to 240 UOE per half minute may be obtained. Furthermore, this new modification need not be removed when the trainer is packed in its storage case. A further modification introducing tracking errors as well as stereoscopic change was developed at Fort Lauderdale but this modification had not yet been reported at the time of writing.

The M2 Trainer as a selection test was among the tests on the first battery recommended by NDRC. (4) This test was given at successive testings at Fort Eustis and it was found that the mean scores on the second and third trials are independent of the test administrator of these trials. (484) Here was some evidence that preliminary instructors produce differences which carry over to the test results but these differences are not large. The time required for preliminary instruction depends largely on the experience of the instructor. As a result of this experience the correlations between trials were found to vary from 0.74 to 0.89 for aerial targets and from 0.64 to 0.75 for fixed targets.

One disadvantage of the M2 Trainer as a test instrument was that it could only be given as an individual test, requiring a considerable expenditure of both subject and instructor time. It required approximately 20 minutes for initial instruction; 5 minutes up to binocular observation and 3 additional minutes to see stereo.

The correlations between fixed and aerial scores on the four trials varied from 0.72 to 0.86. In regard to the reliability of the test correlations for aerial targets for the different trials varied from 0.74 to 0.89 and for fixed targets from 0.64 to 0.75. These correlations are satisfactorily high.

In another experiment dealing with the comparative reliability of fixed and aerial trials with the M2 Trainer, it was found that deviations from true score in any trial are independent of deviations from true score in any other trial. (495) In another study it was determined that the subjects who see stereo immediately upon looking into the M2 Trainer performed, as a group, considerably better than those taking a longer time. The difference is largely due to performers in this group. Much of this material is summarized in another place. (370)

As the result of the subsequent testing with members of the height finder classes at Camp Davis, the reliability of the M2 Trainer on a test-retest basis was found to be 0.71. (73) Validation with actual performance scores on the height finder in the School at Camp Davis give the following correlations with M2 Trainer scores of this picked group: for variability score, 0.41; and for sum of variability and course error scores, 0.43. Both of these correlations are well above the 1 per cent level and hence are highly significant. They are, however, smaller than the coefficients obtained for the Eikonometer. A systematic study was made of the cutoff scores in terms of instructional cost. Using a standard cutoff score of 110, only 40 per cent of the men would be admitted to the school and it would be necessary to screen 256 men in order to obtain a class of 111 men who would meet the criterion.

As a result of these data it was recommended (73) that the M2 Trainer test be dropped from the selection battery. It was further recommended, however, that for field and other use where the Projection Eikonometer may not be available, men be accepted for training who score highest on the M2 Trainer test, none being accepted who score below 90.

13.5.3 The Eikonometer Test

The Eikonometer test in one form was recommended in the first battery for the selection of range

finder operators, along with the M2 Trainer test, as the basis for determining stereoscopic acuity. (4) In the final selection battery this test is recommended as the only basis for such selection but with a slightly different cutoff value. (73) In its final form, the instrument consists essentially of two small projection lanterns, an aluminized non-depolarizing screen, and a system of Polaroid viewers. Two vertical line images are projected on the screen by the projectors. These images are projected through polarizers so that, when viewed by the subject through the Polaroid viewing system, only one line is visible to each eye. Each pair of polarizers and analyzers, has its axes of polarization at right angles to the other. By means of gears coupling lantern slides in the projectors, the line images are rotated in opposite directions. The lines may be set manually to an extreme deviation of 10 degrees from vertical in either direction. When the motor drive is started, the lines return slowly toward the vertical at the rate of 1 degree every 5 seconds. The subject fuses the images binocularly and sees a single line tipping toward or away from him. When the line appears to be vertical, the subject stops the motor drive by pressing a switch. The position of the lines at the time of the subject's response is determined by reading a scale on the shaft which rotates the slides. This is known as the Stereo-Vertical Test with the Projection Eikonometer. After practice trials, the subject is given 30 test trials in three groups of 10 each. The raw score is converted into a standard score. This instrument was originally built for the examination of a single subject at a time. However, a multiple recording device has been developed so that it is now possible to test six subjects simultaneously.

There has been a great deal of work on the development of the final form of this test, both in regard to instrumental development and to the use of the instruments. The original Eikonometer was an instrument developed to measure quantitatively various kinds and degrees of abnormal perception of special relations of the sort met with in the condition known as aniseikonia. A description of the instrument used in the early series of testing will be found in a May 1942 report. (354) The description of the Multiple Projection Eikonometer and detailed description of the administration and scoring of the test appeared under date of December of the same year. (370) This account also indicates modifications in both the instrument and the method of administration which resulted from experience in testing at Fort Eustis.

In Class 8 at Fort Monroe, 15 men were examined on the Ophthalmo-Eikonometer, 20 on the Space Eikonometer, and 28 in the leaf room in an effort to determine the presence of aniseikonic effects. The study was reported as early as July 1941. (469) Because the Space Eikonometer and the leaf room seemed to differentiate the subjects better than the other test, these were also given to the men in Class 9. Six men in the group failed to pass the standards for graduation. Of these, the leaf room test selected three but also selected as defective two men who passed. The data of the Space Eikonometer differentiated the two groups. Case studies of the six men who failed to graduate are appended.

In the screening tests for Class 11, three tests were given with the Space Eikonometer: axis 90 degrees; axis 180 degrees; and the cyclo tests. It was concluded that the axis 90 degrees test gave no improvement in prediction over the use of the combined axis 180 degrees and the cyclo tests, and it was decided to weight the axis 180 degrees test tenfold in the development of a single score. (471)

A detailed study was made of the reliability of Space Eikonometer settings on Class 11 for both the axis 180 degrees and the cyclo tests. (482) It was found for the axis 180 degrees test that the variability from day to day is rather less than would be expected from the mean error score of a single day. On the other hand, there was evidence for the cyclo test of such day to day variation. In another study of repeated tests on Class 12, axis 180 degrees; cyclo and the stereo-vertical tests were given. (483) The results indicate that the ability measured in all three tests is identical. Retest at Fort Monroe gave significantly different mean scores from those previously obtained at Fort Eustis, probably because of a learning factor while at the Height Finder School. It was also found that the Space Eikonometer gave a significantly different mean from tests on the Projection Eikonometer. This again may be due to learning, inasmuch as the tests with the Space Eikonometer were given before the training of these men had begun.

An analysis was made of the results of the second testing at Camp Eustis in July 1942. (492) In regard to reliability of the measure, the test-retest reliability, with administrator differences eliminated, is 0.46. The Eikonometer Test correlates at the 5 per cent level with the M2 trainer test but not significantly with the Wulfeck Group Test of stereoscopic ability. In another study it was also found that there is little

relation between stereo acuity, as measured by Eikonometer Tests, and visual acuity. (493) In other words, within the range of acceptable visual acuity, there is little if any relation between these two abilities. This finding emphasizes the need for the inclusion of a test specifically to measure stereoscopic acuity in any battery for the selection of stereoscopic range finder operators. Outside the range of visual acuity eligibility there is some indication of poorer stereoscopic performance, as would be expected.

At the end of the third Eustis testing, stereo-vertical scores had been obtained from 207 men making comparison of distributions of scores possible. It was found that the distributions for the two groups were very similar and did not vary significantly in regard to any measure. (494) Hence it was concluded that the test had been adequately standardized. It had already been found that administrator differences for these tests were of negligible magnitude. (497) In this same study the reliability of the stereo-vertical test is given as 0.52, which is higher than that for axis 180 degrees and more than twice as high as that for the cyclo test. Hence it was concluded that of these three tests the stereo-vertical is subject to less serious error.

The introduction of a motor drive in the stereo-vertical test proved to eliminate much of this error. (500) Results of the new form correlate with the older form 0.44. The reliability of the new form on a test-retest basis is 0.42. Both the old and new motor-driven forms of the stereo-vertical test were validated on the members of Class 12 at Fort Monroe. (501) The new form of test correlates 0.39 with log aerial UOE, and 0.28 with log UOE for fixed targets.

The number of individuals eliminated during the Fort Eustis testing will be found in the monthly reports. (370) A summary of the test with regard to validation and standardization up to July 1942 is given elsewhere. (357) Between June 1, 1942 and May 31, 1943, of the 37,500 soldiers' records examined only 6,242 survived the earlier tests to be eligible to take the stereoscopic acuity tests. Of these, only 1,474 succeeded in passing these tests as well.

At this point of development, control of these selection experiments passed to the Committee on Service Personnel – Selection and Training, NRC and subsequently to the Applied Psychology Panel NDRC. Working with the selected classes at the Height Finder School at Camp Davis, the Projection Eikonometer was found to have a reliability of 0.81 on a test-retest basis. (73) In regard to validation, the Projection Eikonometer test correlated –0.51 with variability score and –0.50 with sum of variability and course error score for performance on the range finder after training. Both correlations are in the right direction and both are highly significant at the 1 per cent level. At this time a change was recommended in the score for qualification of training from a standard score of 110 to a standard score of 115. This would necessitate screening 236 men (who had passed all of the other tests) to obtain a class of 108 men, of whom it may be expected that 100 will meet the graduation criterion after proper training. In this same report it was recommended that the Projection Eikonometer alone be used as the test for stereoscopic vision, with the M2 Trainer Test as an alternate in the field or in such places as an Eikonometer instrument might not be available. Following this recommendation, a manual was published for the adjustment and operation of the Projection Eikonometer. (146) Illustrations of the instrument will be found therein.

Another study was made of the relationship between test scores obtained on the single and Multiple Projection Eikonometers. (153) Small and insignificant differences were found between the scores for two groups of 100 men each tested by the two methods. Hence the Multiple Projection Eikonometer, which permits simultaneous testing of six men, is recommended for use over the single Projection Eikonometer which necessitates the testing of each man singly. By this means a very considerable gain in testing time is effected and this is further strengthened by the results with the multiple instrument indicating that the position of the viewing subject does not influence the test score.

13.5.4 Relation of Visual Acuity to Stereoscopic Acuity

Finally, the relationship between visual acuity and stereoscopic acuity was reexamined to see whether lowering the present standard of visual acuity would result in a greater number of men passing the stereoscopic test, thus increasing the pool of men eligible for training as stereoscopic range finder observers. (76) To determine this, 1,052 soldiers were permitted to take the tests of stereoscopic vision at Fort Eustis, even though they failed to meet the usual standard

of visual acuity of at least 20/20 in each eye (unaided). Analyses of the results show that although the elimination of the test for visual acuity would produce a slight increase in the number of men who qualify on the stereoscopic tests, the burden of testing would be greatly increased because a large majority of men with vision poorer than 20/20 fail the stereoscopic tests. Thus, the relaxation of the visual acuity requirement would be uneconomical in testing time. However, only 12 per cent of the men with visual acuity of 20/20 or better subsequently pass the stereoscopic tests. The test for visual acuity, therefore, may be considered an effective and time-saving screening device for the stereoscopic tests, but it does not in any sense replace the stereoscopic tests for the selection of stereoscopic range finder operators.

13.5.5 Miscellaneous

The tests for the selection of stereoscopic range finder observers have been in use in the Army at the three Antiaircraft Replacement Centers at Fort Eustis, Camp Callum and Camp Hahn. In addition, a number of mobile testing units were activated which tested Army men at training centers or isolated units in the field in the United States. Some time later Navy men were tested at the Fire Control School at Fort Lauderdale and also many of the men of the USS New Jersey were given the tests as the basis for the assignment of men to duty on board ship.

There were some difficulties in regard to the validation of these tests. In the first place, the numbers of students in the classes at the Height Finder School at Fort Monroe were small and considerable time was required before a sufficient number of cases could be collected for adequate statistical treatment. Secondly, and this was particularly true in the early phases of the war with the very rapidly expanding Army, the mission of the School was properly and necessarily to turn out as many of the best trained stereoscopic observers as possible. This led to great homogeneity of the men in the classes while heterogeneity and variability among the men is necessary for real validation of the basis of their selection. This factor was overcome with Classes 5, 6, and 7 at the Height Finder School at Camp Davis, who were selected so that their scores on the Projection Eikonometer and the M2 Trainer were representative of a random sample of Army population, although they had passed all the other selection tests.

There was difficulty, also, with performance criteria on the range and height finders which must form the basis for validation of any selection test. The early criterion for the Height Finder School was a variability score in UOE. This was unsatisfactory inasmuch as it gave no adequate estimate of accuracy of true range. Finally, a sum of variability and course error score was added to the variability score to take account of this factor. These have been discussed above, as has also the difficulty with the five point scoring system employed by the Navy.

Seven tests of stereoscopic acuity were administered to 288 soldiers at Fort Eustis. (84) This was done for the purpose of determining the interrelationships among the seven stereo tests, the agreement of these tests in selecting men with "good" and with "bad" stereo vision. The seven tests of stereo acuity were:

1. Wulfeck Vectographic Test
2. Bausch and Lomb Ortho-Rater Stereoscopic Test
3. Keystone Stereoscopic Tests
4. Projection Eikonometer
5. M2 Trainer
6. Vectograph Pursuit Test
7. Dearborn-Johnston Test

An examination and statistical treatment of the results indicate the following: (1) there is no evidence that order of test sequence significantly influenced the scores made on any of the tests; (2) the intercorrelations between tests range between 0.10 and 0.53, indicating in most cases small but significant positive relationship; (3) the tests show low agreements in picking men above the 75th percentile and below the 25th percentile.

The Applied Psychology Panel has reported a follow-up study of the efficiency of the Projection Eikonometer Test in predicting the performance of stereoscopic height finder observers. (101) In order to evaluate the continued operation of the Projection Eikonometer as a selection device, the original validation data obtained in the previous study, with a population of stereoscopic height finder operators from Camp Davis (Classes 6 and 7), have been compared with data from operators in subsequent classes (11 through 18). Using these sets of data, a comparison was made of the relationship of scores on the Projection Eikonometer to two Height Finder School

performance criteria—the variability score and the combined score, which is the sum of the variability score and the course error score.

Results for the two groups are practically identical. When a selection standard of 115 on the Projection Eikonometer was used as a cutoff score, 7.1 per cent of the 42 eikonometer passes from the former group failed on variability score, as compared with 7.9 per cent of the 126 eikonometer passes from the new group; and 11.9 per cent from the former group failed on the combined score, as compared with 10.3 per cent from the new group. Significant critical ratios were found between these percentages and the percentage of failures when the Projection Eikonometer was not used as a selection requirement for admission to stereoscopic training.

13.6 TESTS OF EMOTIONAL STABILITY

In the early days of the war, before the extended development of radar, it was obvious that the range and height finder crews must have a high degree of stability. If any one of the team should break in combat the battery would be out of effective action because either no information would be fed to the director, or this information would be inaccurate and incorrect. Hence some attempt at appraisal of emotional instability was made early in the Fort Monroe testing. The two-hand coordination test has previously been mentioned as well as pulse rate, blood pressure, electrocardiogram and basal metabolism. None of these seemed to correlate with range finder performance. (360, 367) Actually, there is no reason to believe that they should because the ranging performance criteria were not obtained under emotional stress.

The Bernreuter Personality Inventory and the NRC Test were given to Classes 8, 9 and 10 at Fort Monroe (480, 481) with no evidence of relationship between the scores and performance as measured by Σ log UOE. These results are summarized elsewhere. (357) These men were also interviewed by a trained psychologist and the data obtained did not seem to show any relation to height finder performance. As a result, similar tests were dropped from the Fort Monroe battery.

However, the effects of emotional tension on range finder performance and the assessing of emotional stability remained still a major problem. The group at Brown University attacked the problem of determining beforehand which individuals were likely to break down under battle conditions, so that they might be screened out, eliminating the possibility of their occupying key positions in a battery.

13.6.1 Experiment with British Seamen

In October 1941 an opportunity was afforded, through the courtesy of the British Navy, to examine six men of HMS Dido, all of whom had seen considerable action. Two of these men had shown "signs of nervous strain," while the other four had conspicuously continued to stay at their tasks during the action—two of the latter being range takers. These men were tested for three days at Fort Monroe and for four days at Providence, R. I. (2) None of the investigators knew which men had broken during action until all of the results were in. A conference was held about a month after the testing for a discussion of the results. In this way it was hoped to get a rough initial validation of certain screening tests which had been developed or proposed.

These six men were given a complete refraction and very complete ocular functional test as well as tests of ocular tremor at Fort Monroe, and also examination for color blindness and size of ocular fields at Providence. There was no indication from the ophthalmological tests as to who might break in action except one man (a range taker who had shown conspicuous bravery) who had a considerable ocular tremor.

Tests of intelligence indicated that the men were of average intelligence or better, with relatively little variation within the group. At Monroe the men were given electrocardiograms which were all negative; basal metabolism which showed one of the very good men to have an abnormally low rate and also no pathology in breathing or blood pressure.

Electroencephalograms were given at Providence, taken from four cortical areas simultaneously. For both of the men who had broken in combat, abnormal records were obtained with the men in resting condition. In a second period, with unexpected light and sound, no differentiation was apparent. In a third period, with two minutes hyperventilation, one of the men who had broken gave slower brain waves from his frontal cortex.

In a fourth period of low oxygen, one of the men

who had broken showed abnormal breathing, as well as one of the good men. The other questionable subject showed abnormally slow brain waves and an abnormal pattern of breathing. The case of one of the excellent men was dramatic and of the greatest interest, inasmuch as, after two minutes of the reduced oxygen technique, he showed abnormally slow brain waves which turned into waves of 2 per second of large amplitude. This was followed by an actual convulsion of 10 seconds duration with clonic jaw movements and loss of consciousness. Hence the electroencephalographic technique not only differentiated the men in the group who had broken in action but also detected another individual with unusual and unsuspected sensitivity of the cortex to low oxygen. However, the widespread adoption of this technique seemed impossible at the time because of the extremely small number of individuals competent to interpret such data at the clinical level.

The men were also given a psychiatric examination. This indicated no adequate differentiation among the men of the group. The same was true of the Rorschack Ink Blot Test. Both tests rated one of the suspected men as an extremely well-adjusted individual while both differentiated the other from the group.

Paper and pencil tests for neurotic tendency, self-sufficiency, introversion, and social dominance were given the men without differentiation. This was also true for tests of mechanical comprehension and the perception of spatial relations.

A number of objective tests were also given but these gave no real basis for determining which men had broken in action. Among the objective tests given were the two-handed coordination, manual steadiness, and reaction coordination tests at Brown University. Certain special objective tests consisting of some task had been developed. The scores taken under normal conditions were compared with performance when severe electric shock is experienced and/or apprehended. One of these was a stereoscopic pursuit apparatus which did not differentiate among the men. Another ineffective technique involved the effect of strong electric shock on the immediate memory for numbers. A third technique was more successful. This involved the reaction time for binocular fusion with shock and also with the galvanic skin reflex determined. This technique does not involve learning and the reliabilities seemed good. By this test the two men who had broken during action were differentiated from the men who had shown conspicuous bravery during action. A more extensive report of this material will be found in another place. (576)

Although the results of this testing were by no means conclusive, the results were encouraging enough to warrant continued research on the problem. A number of studies were made by the Brown University group who concentrated on the problem. Research in this field has always been recognized as one of the most difficult areas in experimental psychology. The determination of emotionally prone individuals has always been considered to fall largely in the field of psychiatry. No objective psychological measures had been devised up to this time and hence the research was practically in a virgin field.

The apparatus for determining the reaction time for binocular fusion with shock is described and the method of administration of the test is outlined. This is a test which must be given individually and which requires considerable time for each subject. (117) Certain easy conditions were set up in which the images to be fused were close together while in other conditions the images to each eye were far apart and fusion was difficult. The reaction times for the difficult condition proved to be reliably longer than those for the easy condition. Experimenting with laboratory subjects, it was found that there were noticeable individual differences with regard to the effect of electric shock. A few subjects show little effect of shock, but others show a noticeable lengthening in the time required for fusion when shock was applied. In certain of the series, apprehension of shock was employed. The trials occurred when electrodes were placed on the subject but no shock was given. Again individual differences were found in regard to the effect of apprehension. Very noticeable are those cases in which apprehension slowed down the fusion response. The detailed report of the experiment on the men from the HMS Dido has already been discussed. (118)

Very early in 1942 a situation developed by which it was hoped to obtain some validation of these tests against battle experience. At Fort Monroe a skeleton battery was formed which was to be sent to some "hot spot" in Britain and be placed alongside a British antiaircraft battery in an effort to obtain an assessment of the systems of fire control and of the effectiveness of the weapons of the two armies. Opportunity was given to test these men for emotional

stability. Unfortunately the skeleton battery was never sent overseas as a unit and hence no validation data was obtained from this experiment. A total of 43 of the 48 men completed all of the tests. Two personality tests (NRC Personality Inventory and the Willoughby Test), three tests of motor performance (stereoscopic reaction time, steadiness and pursuit test), a test of immediate memory, an intelligence examination (Wunderlich Personnel Test), and measurement of change in skin resistance were given each subject. The effects of electric shock were noted in all the performance tests. Each man was tested individually, except in the paper and pencil tests. Each of the tests is described and alternate methods of scoring are discussed. The men were also given an examination by a trained psychiatrist. The men were placed in rank order of susceptibility to emotional break under stress but, as was pointed out above, this group was not sent overseas and hence no validation from combat experience was obtained.

Results of the testing of 207 undergraduates at Brown University are reported. (120) They were all given a group of four paper and pencil tests; the NRC Neurotic Inventory, the NRC Troublemaking Inventory, the Willoughby Test and the Wunderlich Personnel Test. Contrasted with those of the standardizing group, the results indicate relatively higher sides on the NRC and Willoughby neurotic inventories; their troublemaking scores do not differ appreciably from those of a standard group, and they give relatively high scores on the Wunderlich Personnel Test. A further analysis of the data for the NRC Neurotic Inventory indicates that the differences between the scores of the Brown students and the standard group may be attributed to factors of intelligence and/or educational opportunity. (121) The results are merely suggestive and are obtained by contrasting the scores of the Brown students with those of the Fort Monroe skeleton battery, some sailors at the New London Submarine Base, and the sailors from HMS Dido.

13.6.2 Validation of Psychological Tests

An opportunity at validation of these emotional stability tests was afforded by opportunity to work at the U. S. Submarine Base at New London. Here the men who have volunteered for submarine service are given training for this special work. Part of this instruction is training in the use of the "escape lung". At the final stages of this special training the men must step out into a tank of water 30 feet below the surface and slowly rise to the surface, utilizing the emergency apparatus. The men can also volunteer to come up from a level 100 feet below the surface. It had been found that a certain small proportion of the men refused to take the escape lung tank test, even though they had already demonstrated to their own satisfaction that the escape lung was entirely adequate. Some had sufficient upset so that they had to be removed from the tank. All such cases were sent back to surface ships. A first report (122) outlines the results of testing the first 25 such individuals. This number was subsequently greatly increased and the enlarged group will be discussed as a whole below. However the report indicates that the reliability of the reaction time to fusion test, on a test-retest basis, is above 0.50 which is satisfactorily high. Case histories of 26 of the submarine men who failed or refused tank escape training are given in the report.

Although the reaction time to binocular fusion test seemed to validate best with emotional instability as a predictive instrument, it must be given to each subject individually and requires considerable time for administration. The search was continued for some paper and pencil test that would correlate highly with the performance test and could be given simultaneously to a group of subjects. The early testing indicated that the NRC Neurotic Inventory gave the greatest promise for this substitution. An analysis was made of this test from the scores of 316 individuals (soldiers, sailors, and college students). (123) These subjects were fractionated into groups of comparable intelligence and the results indicate that the scores of the NRC Neurotic Inventory are indeed a function of intelligence. From the level of very low intelligence to average, there is no change in the position of the percentile curves for homogeneous intelligence groupings as intelligence increases. As intelligence increases from average to a higher level, the percentile curves for homogeneous intelligence groups are displaced more and more toward the high score extreme. Hence a rough correction, based on intelligence score, is suggested. Also a preliminary analysis of the scores of this test from 886 "normals" and 37 "cases" indicates that a new method of scoring may be desirable in the application of the test to service personnel.

The next attempt at validation reports the admin-

istration of a battery of tests to 41 men who had shown emotional instability and comparison of these with a standard group of 72 individuals. (124) The emotionally unstable group were all from the New London base. The results indicate that the binocular fusion reaction time test was promising, inasmuch as one measure placed 66 per cent of the validating cases with a certain score range, while only 18 per cent of the standard subjects fall within the same range. Also, the NRC Neurotic Inventory score, corrected for intelligence, seemed promising on the selective side. About four times as many validating cases score above the 90th percentile as did standard subjects. The Willoughby test did not seem promising. Finally, the setting up of arbitrary scores of a battery would screen out 86 per cent of the validating group and only 29 per cent of the standard.

A standardized form of the final form of the apparatus for testing binocular fusion reaction time and rules for the administration of this test are given in detail. (125)

A comparison is made of the Wunderlich and Otis Intelligence Test scores for submarine men and Brown University students. (128) These tests were given to 412 submarine men and 159 students, in order to establish norms for the conversion of the scores from one test to the other. This was established. The shock fusion results from 258 submarine men were compared with the psychiatric ratings of these same men. The reliability coefficient of the test was very high, and in corrected form was 0.84. The results indicate that a score of 0.10 constitutes a good cutoff value; only 26 per cent of the good men are rejected by this score while 60 per cent of the poor men are rejected.

An attempt was made to evaluate the procedures used at the New London Base. (130) Comparisons of the total submarine school population and the subjects used in the Brown research were made in regard to physical examinations, escape tank performances, school grades and neuropsychiatric classifications. It was found that the population at the New London Base was comparable to the total population in the Submarine School in the light of these findings.

The two-hand coordination test was given to a random selection of 257 submarine men and cutoff values for the test were determined. (132) An item analysis was carved out on results on the NRC Inventory consisting of 410 "normals" and "questionables" (the "good" group) and 82 "bads" and "disqualifieds" (the "bad" group). (134) The differentiation into the various groups resulted from the routine psychiatric examination. The item analysis resulted in the development of a scoring stencil for this test. If the 90th percentile is used as a cutoff score, the stencil rejects 36 per cent of the "bads" and only 4 per cent of the "goods". A cutoff score of 85 percentile would reject 40 per cent of the "bads" and 9 per cent of the "goods".

An attempt to evaluate the selectivity of these tests used as a battery was made upon 306 "goods" and 71 "bads" at New London on the basis of psychiatric criterion. (135) Included in the battery were the following tests: Otis Intelligence, Reaction Time for Binocular Fusion; Two-Hand Coordination Test, and NRC Neurotic Inventory. Passing scores were established for each of the tests. The NRC Troublemaking Inventory and the Willoughby Personality tests were excluded as not significant. A combination of three of the tests (Intelligence, Neurotic Inventory and Two-Hand Coordination), each with appropriate cutoff scores, rejected 68 per cent of the psychiatric "bads" and 24 per cent of the "goods". It should be noted that the category of "goods" include those classified as "questionable" in the psychiatric examination. The Neurotic Inventory and the Fusion Reaction Time Test were found to correlate highly, 0.48, and hence the question was raised as to the advisability of retaining both tests in the battery. The Neurotic Inventory was retained because it was a group paper and pencil test, while the other required lengthy individual examination. This study led to another item analysis of the NRC Neurotic Inventory (137) on a tested population of 728 submarine men whose psychiatric rating was known. Each item of the test was weighted. With a cutoff at the 95th percentile, the new stencil failed 3 per cent of the "goods" and 13 per cent of the "bads", at the 90th percentile, 6 per cent "goods" and 27 per cent "bads"; at the 85th percentile the test rejects 9 per cent of the "goods" and 39 per cent of the "bads."

Until this time the tests at the New London Base had been validated only against psychiatric criteria which itself may be questionable. In another report an attempt at validation was made against tank performance and officer's judgments as well. (140) Of 984 men tested, 25 per cent of the psychiatric "goods" failed one or more tests while 62 per cent of the psychiatric "bads" were rejected. Of the 45 men who

showed abnormal behavior in the tank, 30 (or 67 per cent) failed one test or more, as against only 30 per cent of the normal group. The results for officer's judgments were less conclusive. It was believed that the criterion of failure on a single test was too great in selection cost, inasmuch as too many of the good men would be eliminated. Permissible rejection rate for psychological causes might be set at 8 to 9 per cent. To meet this rejection criterion the following schedule was set up. Failure in any two tests, or a score of 80 or lower on the Otis test would disqualify the candidate for submarine service. Applying this new schedule on the same population gave the following results: 5 per cent of the psychiatric "goods" against 26 per cent of the psychiatric "bads" were rejected; 20 per cent of the tank failures against 7.5 per cent of the normal group were rejected. As an additional criterion, blanks were sent out to the Fleet for officers' judgments of performance of the men tested after a tour of submarine duty. The final battery considered in this experiment included three tests: Otis Intelligence and the Two-Hand Coordination tests and the NRC Inventory. A more detailed analysis of the 45 escape tank failures is given elsewhere. (141)

13.6.3 The Personal Inventory Test

The derivation, construction, administration, and validation of the NRC Personal Inventory are contained in another reference. (144) In its final form this consists of a ten page booklet with 145 items of forced-choice and yes-no type. These questions are based on a statistical analysis of 254 naval and military case histories, of which 140 were obtained from psychiatric cases and 114 from normal personnel. The item differentiation was determined by administering the test to 84 early psychiatric discharges and 1,004 psychiatrically approved enlisted men at the U. S. Naval Training Station at Newport, Rhode Island. Sixty items differentiated between these two groups with a critical ratio of 2.7 or greater and a scoring stencil on them was devised. The validity of this test was determined by giving the Inventory to additional groups and comparing the respective percentages identified. These validation results are: of 124 Newport psychiatric cases — 52 per cent were identified; of 25 Chelsea Hospital psychiatric ward cases—60 per cent; of 50 New London Base psychiatric "bads"—36 per cent; of 5.08 Newport Base normals—only 4 per cent, and of 133 New London Base "goods" only 2 per cent. By a split-half technique, the reliability of the test is 0.77, which is high. It was concluded that the usefulness of the Inventory in identifying an appreciable proportion of undesirables for immediate psychiatric examination was demonstrated. This was important because, with the rapidly expanding armed forces it was impossible to give every new enlisted man a psychiatric examination, as had been the previous Navy procedure, because of lack of trained examining personnel. Detailed analysis of some of the testing at the Newport Naval Training Station will be found in a single report. (46) An extension of the analysis of the test battery against tank performance will be found in other reports. (141, 157) A summary of the escape tank training will be found in an appendix to this report. Finally, additional item analysis and evaluation of the scoring stencil for the Personal Inventory are reported. (167) This item analysis is based upon a study of the testing of 1,004 normal enlisted men compared with 385 early psychiatric discharges at the Newport Training Station. This analysis disclosed that all 60 of the items included in the original scoring stencil continued to differentiate these two groups. The critical ratios of these 60 items ranged from 2.4 to 15.9 and 49 were common to the 60 most significant ones emerging from this analysis. Application of the stencil to a new group of 508 normal recruits and 184 psychiatric discharges produced a similar result.

Much of this material has been gathered together and summarized in a single report. (156) From a consideration of these results it is recommended that the submarine group adopt these procedures with alternative plans suggested depending on allowable rejection rates. These tests were subsequently applied in a number of training stations for the Navy, Marines and the Amphibious Forces.

A short form of the Personal Inventory has been given a preliminary validation. (169) This form consists of 20 highly differentiating items from the original inventory, conveniently arranged on one side of a single sheet. It takes less than 10 minutes to give and can be scored at the rate of several per minute. Validity, as determined by comparison of scores for 538 normal sailors and 263 psychiatric ward discharges at the U. S. Naval Training Station at Newport seem promising. For example, a critical score

of 8 identified 69 per cent of the psychiatric discharges and included only 4½ per cent of the normals. The validity of each item also proved satisfactory, with critical ratios ranging from 3.8 to 16.7. Formats A and B of the Personal Inventory Test were given in various ways to 2,648 enlisted men to determine if the two forms were comparable. (85) The forms are identical except in the matter of mechanical arrangements for writing on the answer sheet. The results show that the first half of either test correlates with the last half of the other test as well as it does with its own last half. The results of this and other analyses indicate that Formats A and B are comparable.

A short form of the Personal Inventory consisting of 20 highly significant items on a single sheet was developed. (89) It can be administered in 10 minutes. This form was used for test of 571 "boots" and 491 special assignment men at Newport before the psychiatric interview which was given some two months later. Comparison of Personal Inventory scores and psychiatric dispositions revealed significant differentiation. For example, in the "boot" group, a critical score of 9 on the Personal Inventory identified 50 per cent of the discharges while including less than 6 per cent of the non-discharges. Hence the Inventory's usefulness in identifying an appreciable proportion of the psychiatrically undesirables seems to have been demonstrated.

In an effort to evaluate the Personal Inventory further as a selection instrument, the service records were examined of 1,466 men who had taken this test a year before when entering "boot" training at the Newport Naval Training Station. (92) All of these men had been regarded as psychiatrically normal at this time testing—the discharges and psychiatric ward observation cases having been excluded. The object of this present study was to relate the following information, whenever it was available, to the Personal Inventory score: (1) General Classification Test Score, (2) age at time of entering Navy, (3) rating one year after initial testing, (4) conduct record and (5) active or discharge status.

The following results are true for the entire group and also for the 1,007 men for whom complete data were available. (1) The Personal Inventory identified a significant proportion of the 52 men who were later discharged. Twenty-one per cent of these had received scores of 18 or above on the personal inventory as compared with but 4 per cent of the active men. The mean score for the discharges was significantly higher—4.3 points (Critical Ratio 3.9)—than for the active group. Of the seven men scoring 26 or over on the Personal Inventory, all had been discharged. (2) The Personal Inventory showed some tendency to differentiate conduct cases. The mean score for the men with good conduct records was 9.1 as compared with 10.8 for the men with some conduct offense and 11.9 for those with more serious offenses. (3) The Personal Inventory showed some tendency to differentiate rated from non-rated men. The mean score for the rated was 8.3 as compared with 10.0 for the non-rated men. (4) The Personal Inventory showed but moderate correlation with the old form of the General Classification Test. The correlation between the two was 0.28 ± 0.02. This is sufficiently low so that the use of one test in no way precludes the use of the other. (5) The Personal Inventory showed virtually no relationship to age at time of entering service, the correlation being 0.01 ± 0.02. (6) The General Classification Test tended to differentiate discharges, but to a decidedly lesser extent than the Personal Inventory. It tended to differentiate conduct cases to a slight degree, and to differentiate rated men somewhat more sharply than the Personal Inventory. It is pointed out that this may have been due in part to the availability of the General Classification Test Scores in the assignment of ratings.

Another experiment from Brown University is concerned with the reliability of the short form of the Personal Inventory and its relation to the long form, and with the relation of scores on the long and short form to the General Classification Test scores. (94) At the Classification Center at Solomons, Maryland 426 newly arrived men were given both forms of the Personal Inventory. The split-half reliability coefficient for the short form is 0.81. This coefficient is as high as a similar value for the long form. The correlation between scores on the short form and subsequent scores on the long form was 0.84. Consequently the short form of the Personal Inventory is highly correlated with the long form and its reliability is comparable as well. It was also found that the product-moment correlation between GCT score and short form score is −0.25 for the 426 men. Previously obtained correlation between GCT and the long form scores was −0.35. Hence it is concluded that the correlation between either the long or short form of the Personal Inventory and the General

Classification Test is not high enough to warrant the elimination of either test because of the use of the other.

In a final report from Brown University is summarized an account of completed experimental research on the development of the Personal Inventory Test. (95) The Personal Inventory is a group test for the preliminary screening of psychiatrically undesirable men. Its items, based on case history dissimilarities between psychiatrically undesirable and normal military personnel, are cast in forced-choice form to promote valid answering. All of the experimental results outlined in the several summaries above are given. The following final conclusions and recommendations are made. Both forms of the Personal Inventory identify a very significant proportion of psychiatrically undesirable men while including but a small proportion of normal Naval personnel. Both are recommended for any or all of the following usages: (1) original screening; (2) selection for special duties where the test proves advantageous; and (3) equalization of units. The short form is more practical for most purposes. It would be expected that for usage, (1) men with scores above a certain critical score (determined on the basis of Service needs) would be marked for further psychiatric interview or examination; usage (2) would involve assignment of men on a basis providing favorable distribution of Personal Inventory scores in given units; usage (3) would involve the Personal Inventory in selection for special duties. In many cases, further research on the relation of Personal Inventory scores to specific job criteria will have to be carried out. The long form would seem preferable for these situations, since it would probably provide a greater number of significant items than the short form. It has been the experience of the investigators that a proctored group, numbering up to 500 men, may be given the long form Personal Inventory in an effective manner. The largest group tested with the shorter form numbered about 200 men.

A general final summary of the work of the project under the Applied Psychology Panel of NDRC will be found in a single publication for both selection and training of stereoscopic height finder operators. (90)

13.6.4 Conclusion

There has been reported above a very large amount of work having to do with the selection of specialized Service personnel. The net results are as follows:

1. A standard set of selection tests for range and height finder operators was developed. Here the problem was to select the "cream" of the candidates and in this the tests were successful. The development of the test battery reached the point where there was not an undue expenditure of examiner time. This battery of tests was adopted early by the Army and somewhat later by the Navy. Too much emphasis cannot be placed upon the need for the selection of the right men for the job of stereoscopic operators because the success of the battery may be largely dependent upon their performance. This was especially true in the earlier days of the war, before the development of radar, when information for the director in regard to range or height was dependent upon the accurate and consistent operation of these men.

2. There has been developed a series of tests to eliminate the psychologically unfit men. It is extremely important to guard against the placing of men, who might break emotionally under battle conditions, in key jobs. The security and efficiency of a whole combat group might suffer as a result. Here the problem is essentially different from that of the selection of stereoscopic range finder observers. For the latter, the very small percentage of the top men was desired; for the determination of the psychologically unfit, it was necessary to remove the lower or poor part of the population tested. These tests for the determination of the psychologically unfit have been used by certain groups in the Navy, the Marine Corps and the Amphibious Forces.

Chapter 14

TRAINING OF RANGE FINDER OPERATORS

14.1 MEASURES OF ACCURACY OF PERFORMANCE

14.1.1 True Target Position

One of the first problems facing the Princeton Laboratory group at Fort Monroe was to determine the true position of a friendly aerial target in tri-dimensional space. Such a determination of true target position is essential as a basis of comparison of the accuracy of range-finder readings. Obviously these data must be more accurate than those taken on the same target by optical and radio range and direction finders. Various methods and types of instruments were considered in connection with this problem. These included nonrecording theodolites, recording phototheodolites, aerial photography, barometric and radio altimeters, multistation microwave instruments, and others. As a result of these tests and for reasons of expediency and economy, the recording theodolites were adopted for use in all later tests of range finders.

It was found that the nonrecording theodolites used were not accurate enough (370A, Pp 74-83) and that considerably greater accuracy could be obtained with the photo-theodolite instruments. It was also found that aerial photography, though extremely accurate, was too tedious and difficult a process for the purpose. A theoretical discussion of photogrammetry for this purpose is reported. (346) The results of the comparative tests of photogrammetric and phototheodolite methods are given in full. (362)

The only theodolites which were available were the standard "spotting scopes" (PH-BC-33) used by the Army for photographing shell bursts in order to score antiaircraft target practices. Since these theodolites were not intended for precision work, it was necessary to modify them substantially. It was also necessary to develop and use an elaborate system of calibration techniques, computational methods and formulas, and auxiliary photographic and timing equipment in order to obtain the accuracy necessary for the performance tests of the optical and radio range finders under consideration. These are described theoretically (370A) and practically. (363)

This method was finally developed to the point where it was used successfully, and the modified theodolites and accessory equipment and methods were adopted for regular use by the Antiaircraft Artillery Board and the Antiaircraft Artillery Schools.

The results of this development of apparatus and methods for the determination of true position of an aerial target are contained in a Manual of considerable length. (363) Problems of communication, timing, recording and the like are given in considerable detail as well as description of instruments and tables of organization of personnel. The method involves a two station system at ends of a carefully surveyed baseline with a synchronized phototheodolite at each station. Special theodolite mounts and shelters were provided. The target can be observed usefully only if both theodolites can photograph it. Under the conditions employed, this restricts the working region to a range of about 20,000 yards from each theodolite station, depending on visibility and the film used. The area directly over each station cannot be used because of tracking difficulties there. Complete equipment and procedure at each theodolite station and at the central command post is described in great detail. There is also a complete and detailed description of the methods for analysis of the theodolite data. This involves the reading and adjustment of the photographic film and also the procedure of the computing unit. Special forms were produced to aid in all this work.

In an appendix is treated the problem of errors of alignment in phototheodolites, their measurement, and the correction of phototheodolite data for their presence. Corrections are made for refraction, curvature, and azimuth tracking. All of the test and computational forms are illustrated and alternate computational procedures are also given. The manual thus outlines theory and practice by this procedure in such a way that the method may be readily reproduced by new testing or training units.

A theoretical study (455) indicates that refraction makes the target seem higher than it really is because the effect of refraction will be to move the image away from the principal point of the photographic plate. Corrections must be made for two station data because of refraction, the curvature of the earth and difference in altitude of the two stations. (456) A

study of camera shutter timing was made. (457) The Filmo cameras proved to have a shorter shutter lag than the Cine-Kodak. (459)

14.1.2 Magnitude of Errors with M1 Stereoscopic Height Finder

With the standard of true position of an aerial target solved, the question of size of the errors when ranging with stereoscopic range finders can be answered. The most complete discussion of this topic will be found in a Report to the Services (30) which is attached to a Princeton University report from Fort Monroe. (367)

Three factors are involved in this assessment; the repeatability of measurements (precision), the correctness of the measurements (accuracy), and the uniformity of an operator's performance from day to day (consistency). All three of these factors are discussed. In these reports an attempt is made to present typical data, so that a fair overall picture will result. However, it should be noted that the data upon which the report is based were all taken at the Antiaircraft Artillery School and hence under favorable conditions. Field conditions will not always be favorable, and observers will not always be so well trained. Hence, results will not always be up to the level of those reported. On the other hand, precautions to avoid perspective errors, which have since been discovered, had at that time not been taken. The data, therefore, are not so good as they should be, with equally good personnel, once these errors have been eliminated.

During 1941 and 1942 the Princeton Field Laboratory at Fort Monroe collected 325,000 or more height finder observations, consisting of approximately 125,000 readings on aerial targets and 200,000 readings on fixed targets. Observations were made by special test observers, assigned to NDRC, and by student observers in the Coast Artillery School. Some of the test observers had had considerable training and experience but it is not known how they compare with seasoned observers attached to antiaircraft batteries.

The tests were run for a variety of purposes, thus providing level and dive courses, and crossing, approaching and receding courses at various ranges. The data also include certain comparative tests of different instruments and of instruments of different types.

Precision error, which measures the variability of height finder errors within courses, depends to some extent on the nature of the course, the instrument, weather conditions, etc., as well as on the observer. Nevertheless, the precision error of most observers has fairly well defined limits under reasonable circumstances. Even by the better observers, 1 UOE is about the smallest precision error which can be consistently attained, although precision error on particular courses may occasionally be as low as 0.5 UOE. On level courses, the largest precision error of better observers is rarely much more than 2.5 UOE and even that of inexperienced observers is under 4 UOE most of the time. On dive courses, it is impossible to delimit precision error very accurately on the basis of available data, which is not extensive. Precision error increases to 6 to 10 UOE even for dives which are probably fairly shallow compared with actual tactical dives. However, none of the observers whose results are reported had had very much experience on courses of this type.

Consistency error applies to the scatter of course corrections while accuracy is determined by the proximity of corrections to zero. Therefore, in theory, if an observer is consistent, his readings can be made accurate by setting in a constant calibration, once the correction is known. This procedure is complicated by the fact that the observer's calibrations depend on the instrument used and on observing conditions. In addition, the calibration may be subject to change over a period of time. Thus the consistency error, estimated by periods of a few days, will describe the long-term scatter of course corrections only if observer-instrument calibrations are checked at reasonable intervals.

It was found that consistency error involving both instrumental and operator errors runs slightly larger than precision error for experienced observers. The lowest limit of consistency error is about 1.5 UOE, under ordinary circumstances. A consistency error of 2.5 UOE is still good and it may be as high as 5 UOE at times, even for experienced observers. Not very much is known about the consistency error of poor observers, except that for some men it may become almost indefinitely large. Due to the fact that student-observer data were collected at a time when consistency was not emphasized by the Coast Artillery School, it is difficult to say how much their consistency errors mean. However, it would seem that, with training, most observers ought to attain

a 5 UOE upper limit. Consistency on dive courses seems to be nearly as good as on the level courses run at the same time despite the fact that the observers were not accustomed to dive courses.

In this report, a further analysis is made of course attributes and height finder errors. In regard to the time rate of change of altitude or range, it is observed that, without "aided observing" of some kind, the time rate of change of the quantity to be measured may have considerable effect upon the errors of measurement. When the height finder is set to read height, the stereoscopic observer is measuring what is essentially a function of the change in altitude,—thus the quantity being measured is stationary when the aerial target flies at constant altitude. When reading range, the observer is measuring a function of the change in range. Two major effects are to be expected when the time rate of change of the criterion is large, those of precision and lag. The precision effect is simply an increase in precision error due to increased difficulty of the stereoscopic task. Lag effects are induced by a constant (or nearly constant) time lag between the stimulus and the observer's settings. The time lags may be positive or negative, as the observer lags behind or anticipates. The result of time lags is to introduce a bias in the errors, with the size of the bias depending on the time rate of change. The relevant rate for a height finder is the time rate of change, expressed in UOE per second, of the height, or of the range, depending on which is being read. It is evident that unless the range, or height, are constant, the time rates will rarely be constant over an entire aerial course. As a result, it may be expected that the bias will be subject to a trend for a course with a large time rate.

Analyses of observer's lags in relation to time rate show that the character of the results was such that it seems impossible, with present knowledge, to predict, for a given course, what the lag will be. Lags vary in direction and magnitude for different observers on the same course, and for the same observer even on similar courses, in spite of the fact that on many individual courses the correlations between the errors and the time rate were high.

The type of contact employed by the observer may influence the magnitude of the errors. Two basic types of contact are to be distinguished, broken and continuous. In broken contact the observer deliberately breaks contact, makes a new setting, and then breaks again, yielding about one observation every 5 seconds. In continuous contact the attempt is made to maintain contact at all times. In either case, the observer may indicate when he thinks he has the correct setting. Continuous contact is generally used when the time rate of change of the criterion is large, because of the difficulty in reestablishing a broken contact when the criterion is changing rapidly. However, the question of preferred contact on level aerial courses is still open since not enough is known about the serial aerial function. Differences in precision alone are not sufficient to justify a decision, since the serial correlation (that is, the correlation of errors from observations separated in time on a single course) must be taken into account in considering the effectiveness of prediction. Basically the important question is whether the serial correlation for continuous contact is small enough that the increase in the number of observations results in an effective gain. Curves of serial correlations are given for two expert observers. The results indicate that the serial correlations vary considerably, even for the same man reading on similar courses, and that there is variation by the observer. It is very probable, also, although the data presented provides no relevent evidence, that the serial correlation function varies with the type of course. Figures of descriptive courses are given for observers' reading height or range, level or dive courses, and continuous and broken contact. Finally, the report contains data obtained on 11 aerial courses which supply essentially the raw data for those who wish to calculate with actual height finder observations.

A second report presents a brief analysis of the aerial target performance records of seven of the better stereoscopic observers of the class at the Antiaircraft Artillery School at Camp Davis during December 1942 and January 1943. (238) The data consist of 50 to 60 aerial courses for each of the seven observers, most of these courses at constant height, with heights varying from 2,000 to 3,500 yards and with slant range up to about 10,000 yards. Several are night courses. Each course record consists of five sets of three visually recorded height readings, approximately equally spaced, together with computed true target height for the center reading of each of the sets of three. Since height was nearly constant, this computed height was used for all three readings. The scoring procedure used in the Stereoscopic Observers' Course involves the medium error in UOE for each set of readings. The course error is the

median of the median errors and the variability score is the difference between the two extreme median errors.

It was found that the precision errors for the seven men are not very different in magnitude from the precision errors obtained by the better observers in previous observers of the Stereoscopic Observers' Course. The three best men in precision all had median precision errors of 1.5 UOE. In regard to variability errors, the three best men gave values of 1.5, 2.25, and 2.5 UOE. Of these, only one also appears among the three with the smallest precision error. One of the three most precise had a 50 per cent range of 5 UOE, the largest of the seven observers. It should be noted that the centers of the 50 per cent ranges are, in most cases, quite close to zero, indicating that the personal corrections used were essentially satisfactory. The slight tendency for negative values is explained by the School's preference for slightly short reading of –0.5 UOE. A theoretical discussion of the derivation of performance scores for both continuous and broken contact will be found in a Fort Monroe Princeton Laboratory study. (533)

These performance reports are based upon a series of studies reported by the Princeton Laboratory at Fort Monroe. Eight such studies (391, 398) are concerned with the distribution of errors; eight others with the consistency of mean readings. (289, 296) Eleven studies analyze the homogeneity of variances or the means and dispersions of range finder readings. (407, 417)

A statistical study is reported in an effort to determine of the first observations on an aerial course are worse than the latter ones. (419) A class of 36 men at the Stereoscopic Observers' School read on 48 courses using broken contact. The results indicate that the first observation of an aerial course is subject to larger error, by about 40 per cent, than are the later readings. The first observation has an average error for all subjects of 3.2 UOE against an average for the later readings of 2.3 UOE. The next few readings may be subject to a slightly larger error than the subsequent observations, but the effect is practically negligible after the second reading and probably quite small even for the second. From the same source, a more detailed discussion and determination of the serial correlation function for the same course is determined. (420)

In another early study by the Princeton Laboratory (423) it was found that the standard error of a range determination (based on 10 single readings) may run as high as 15 UOE. This implies that one-third of all determinations may be in error by 15 UOE or more. A calculation of results shows systematic differences as great as 17 UOE are found between instruments; between observers, as great as 16.5 UOE; and between targets, as great as 9 UOE. The elimination of systematic errors due to instrument, observer, and target leaves a residual variation of about 6 UOE, expressed as standard error of a single determination. The minimum error which can be attributed to the observer is of the order of 1.4 to 2.8 UOE. This figure is probably well below the true error attributable to the observer; no data are available from which an accurate estimate can be made, but a standard error at least as high as 4 UOE seems probable. Some portion of the observer's error may be attributed to the method of making contact with the target but the effect of method of contact varies considerably with different observers. It seems probable that uncontrolled temperature effects may account for a portion of the errors.

14.2 TRAINING METHODS AND DEVICES

When the Fire Control Division of NDRC came into the range finder picture, training schools were in operation in both Services, as well as training in the field. Much of this training was on the actual ranging instrument. The M2 Stereoscopic Trainer also existed and was widely used. A separate grade was given for graduation in theory and records and in actual ranging.

The Fire Control Division set up several laboratory studies in the training field. A splendid opportunity was available to the Princeton Laboratory at Fort Monroe because its activities were so closely correlated with those of the Height Finder School of the Antiaircraft Command. Indeed, the students of this School acted as subjects for the Princeton Laboratory experiments. Hence there was continual consideration of training and of training methods over a period of several years at Fort Monroe. This activity was continued when the Army Height Finder School moved to Camp Davis and was extended to special Navy problems at the Fire Control School at Fort Lauderdale. These continuing activities at Camp Davis and Fort Lauderdale were under the direction of the NRC Committee on Service Per-

sonnel — Selection and Training, and later of the Applied Psychology Panel of NDRC.

Several difficulties were apparent early in this development in the evaluation of training and of training procedures. In the first place, the instruments themselves were unreliable. The discussion of these sources of error will be found elsewhere in this report, but it may be mentioned here that they involve such factors as proper calibration, effects of temperature changes, setting of interocular settings and the like.

A second problem was accurate measurement of true target position. This was ultimately accomplished by an accurate measurement of the altitudes or ranges of the aerial missions by using phototheodolite records which were synchronized with the height-finder observations. This will be discussed elsewhere in more detail but some indication of the complications and difficulties with this extremely accurate method may be indicated here. (363) As a result of a year and a half of development, involving a complicated system of recording, timing, intercommunication, and calculation procedures, this system of two-station synchronized phototheodolites placed at surveyed positions and connected through a control panel with one another and with the fire control instruments being tested was standardized. Each phototheodolite records photographically on motion picture film the synchronizing data and the direction of the line of sight from itself to the target at which it is aimed. The developed films provide the data from which are computed the true positions of the target, usually at regular intervals of time. Against these true positions the readings of the fire control instruments or the readings of the operators are then checked.

The method gives results with satisfying accuracy but it requires a relatively large personnel both for operation and for computing. Also, there is a considerable lapse of time of some days before the results can be made known to subjects under training. This is because of the time required for development of film, reading and correction of film for tracking errors, and calculation of the film data. Hence much of the value of the phototheodolite method is lost because, to be really effective, the operator should be able to compare his readings with true range or height immediately and not a week or so after the event.

With the more recent development of accurate radar, it is possible to obtain true range immediately with this instrument with relatively satisfactory accuracy and compare this at once with the readings from the optical instruments. This radar check method has been employed at Fort Lauderdale.

In the very early days, therefore, before accuracy readings were available, the emphasis of the School was on variability of obsrvations only, rather than accuracy or error from true range. Hence the variability score in UOE was adopted by the School for both fixed and aerial targets. Of course, accuracy could be determined and personal constant errors determined for each individual for fixed targets providing these had been accurately surveyed and the true ranges known. With the development of satisfactory methods of determining true range, a course error score in UOE was devised. (73) This is an accuracy score and is the median deviation in UOE from true range. Other possible scores are discussed in the same reference. Distributions of the variability UOE for four classes at Fort Monroe will be found tabulated. (472) For fixed targets these have median values ranging from 0.9 to 1.7 UOE for the different subjects. The limiting values range from 0.5 to 3.0 UOE for fixed targets. The passing grade was 2.0 UOE for the first two classes and 1.55 UOE for the last two classes. For aerial UOE the passing grade was 3.0 UOE throughout. The medians range from 2.35 to 3.0 UOE and the limits of variability range from 1.6 to nearly 8.5 UOE.

One interesting conclusion to be drawn from these tables is the improvement in performance with successive classes as a result of training and selection. The lowering of the passing grade for fixed targets is the best indication. In the case of aerial targets there is little change in the median value. However, in the first class, 50 per cent failed to reach the passing grade; in the next two classes failure was reduced to approximately 18 per cent, and, in the final class, to less than 4 per cent (only one man failed to meet this graduation criterion).

An Applied Psychology Panel report deals with the relationship of errors in height and slant range readings made by stereoscopic observers. (83) Navy range finder personnel perform operations which provide fire control data in terms of slant range. Army height finder operators usually procure data in terms of height. In order to compare the accuracy of these two types of data, stereoscopic observers at Camp Davis, North Carolina, during the last two

weeks of their course, took readings on aerial targets both in slant range and in height. The errors in these readings were computed from true ranges and heights. A comparison was made of variability error scores obtained under each of the two conditions and the correlation between the two variability scores was estimated. It was found that variability scores in slant range is greater than those in height by approximately 2.5 UOE. The scatter of slant range are greater than those in height by approximately 2.5 UOE. The scatter of slant range scores is also greater than the scatter of height scores. However, the obtained correlation between the variability scores in height and those in slant range is 0.71 which is too low to permit accurate individual prediction of one from the other. However, the theoretical relationship between the two scores (given by the coefficient of correlation corrected for attenuation) is 0.93 which is very high. The obtained distribution of variability scores for slant range readings provides an estimate of the distribution of variability scores to be expected from operators of Navy range finders under conditions similar to those existing in the present experiments. The data provide a basis for appreciating the limits of satisfactory performance in making slant range readings as compared with similar limits in making height readings. The general conclusion reached is that the high theoretical relationship between the two sets of scores indicates that the task of reading in slant range differs from that of reading in height primarily in difficulty and not in other important aspects.

14.2.1 Training Instruments

A number of instruments were devised in several laboratories, which were suggested for use as training instruments for stereoscopic range finder operators.

Such an instrument was developed at Tufts College. (557) One great advantage of this instrument is that it has an easily identifiable and adjustable zero point. Real depth is measured rather than decentration as in the M2 Trainer. Hence the deviations are greater for the Tufts instrument and greater accuracy may be expected. For example, on the M2 Trainer, a deviation of 1 UOE corresponds to a decentration of 0.0025 mm while in the Tufts trainer 1 UOE corresponds to about 11 mm of actual depth displacement of the target. This instrument also was supplied with an integrating device which provides scores of average error and of variability during each test. It was however considerably larger than seemed advisable and the field of view was considerably more restricted than that found in the actual ranging instruments. Although this instrument was entirely adequate and extremely useful as a research instrument, it was never recommended for adoption as a training instrument. This instrument is fully described and discussed. (557)

Another such laboratory instrument, developed for laboratory research purposes and satisfactory in that role, was developed by Brown University. (131) This was never recommended as a training device, either; as in the Tufts trainer, the Brown trainer presented to the subject a situation by which a stereoscopically seen reticle was kept in contact with a moving target. In the case of the Brown instrument, this movement is accomplished by decentration of the two images. An adequate scoring device was provided. An apparatus was developed at Harvard University for measuring stereoscopic and vernier acuity but this was never developed as a trainer. (281)

At the Howe Laboratory of Ophthalmology a research instrument developed to study ranging on a simulated high speed diving aeroplane target was subsequently developed into a training instrument. (310) This was adopted by the Navy in modified form and requires a special building for its installation. Ranging is made on a target which appears on a semi-transparent screen on which a moving picture image is projected. Hence size differences as well as apparent depth are produced in the simulated dive. A true zero setting and recording were provided.

In regard to field apparatus, as contrasted with laboratory apparatus, the M2 Trainer originally existed in both Services. In its original form, errors which might be due to tracking or control of range were set in by hand by an operator. It was found that manual control of range change was not feasible because it was not sufficiently slow or smooth or sufficiently uniform from test to test. This latter is a serious objection since it is desirable to compare different observers as well as successive trials of the same observer. No such standardization could be expected with manual control of the instrument.

Hence a method of power control of range change was developed. (371) This was accomplished by coupling a motor driven range drive unit by a rubber belt to the auxiliary range knob. In this way a continuous standard range course was presented to the observer, with the target approaching for 1 minute

and then receding for 1 minute. The course could be changed by the introduction of different cams. In a similar way, tracking errors, of standard form, could be introduced by movement of the azimuth and elevation knobs.

In connection with the activities at Fort Monroe, the Eastman Kodak Company developed a new stereoscopic training instrument. (195) The description of this instrument forms the first appendix to a report from the Fire Control Division to the Services. (17) Although complicated in design, the instrument is essentially as follows. By means of a motor driven cam mechanism, this instrument presents before the eyes of an observer stimuli closely resembling those which would be received if he were observing a real target through a real range finder, and requires him to react to the stimuli by operating controls similar to those on standard stereoscopic instruments. His performance at this task is automatically recorded as an error curve traced on a revolving drum. Adjustments are provided by means of which the instrument can be quickly changed so as to simulate range finders of either stereo, coincidence, or ortho-pseudo type. Discussion of these three types of instruments will be found elsewhere in this summary.

Inasmuch as the instrument has a true zero and an error score may be obtained at once, it was believed to have great possibilities as a training device. This was further enhanced by the development of a mechanism for obtaining an integrated error score. The possibility of this type of training was attractive for three reasons: (1) Training could be carried on in all types of weather and even at night, whereas training on actual range finders is only possible when targets are visible, and even then true range ordinarily is not known; (2) It could be carried out in any location and without the cooperation of aircraft, whereas training with the ordinary range finder requires convenient fixed targets and actual aerial targets; (3) It would reduce the number of range finders required for training purposes, which at that time was highly desirable because of the then critical procurement situation. A complete description of the instrument will be found (159) to include interchangeable range, elevation, and azimuth courses.

As a result of a joint meeting of Army and Navy officers in June 1942, a uniform set of specifications was adopted for both Services (cf. 17 Appendix 3) and the instrument was adopted as the M4 Range Finder Trainer by both the Army and Navy. This instrument would seem to combine all of the features desirable in the ideal range finder trainer.

It was found that the task presented by the standard Mark 2 Stereoscopic Trainer is so simple that its use is limited to very elementary training in stereo ranging. In order to adapt the trainer for more advanced training, a motor drive was constructed which introduces tracking errors and range movement. (91) Tracking errors and range movement are provided by means of three motor-driven cams for a bank of eight trainers mounted on a table. The movement is transmitted from the cams to the trainers by a cable system. Range movement is produced by using the left hand range knob as a pulley around which the cable is wrapped. Movement in elevation and train is produced by attaching the cables to arms which are attached to the horizontal and vertical target displacement knobs respectively. The construction of this system is described and illustrated in the text.

Results with this appliance at the Naval Training School at Fort Lauderdale, Florida, indicate that when range movement and tracking errors complicate the stereo task, men reach a plateau in learning by 32 days, or approximately 190 runs. Previous data indicated that the task presented by the unmodified trainer (three fixed targets) was learned in an average of 80 runs. A training schedule for use with this modification is included.

A comparison of stereoscopic trainers Mark 4 and M6 was made by the Princeton Branch of Frankford Arsenal. (245) Targets favorable to precise settings were used. No differences in instrument performance were found. The targets consisted of (1) a single vertical line, (2) a small circle, (3) the standard trainer target of an airplane silhouette, (4) a Kodachrome slide of a field with haystacks, and (5) a tower as an internal target. It was found, for four observers that performance with these targets was markedly better than that previously obtained with vectographs of difficult ground targets.

As an aid in training, a model of the optics of the stereoscopic height finder has been developed (154) and has been found useful in the teaching of theory. Demonstrations of principles and of certain operations of the range finder can be made with this model which cannot be demonstrated with the height finder itself. A diagram for the construction of the model and of the parts required will be found in this reference.

Inasmuch as most stereoscopic range finder operators are also trained as trackers an instrument for training in azimuth and elevation tracking has been

devised. (77) The instrument is easily assembled and instructions are given for its construction and operation. Such a tracking trainer provides a way of emphasizing, at an early point of the range finder course, the importance of good tracking as a prerequisite of good readings by the range finder observer. The trainer is used to give practice in smooth and continuous tracking. A scoring device gives immediate knowledge of the extent of the tracking errors.

Finally, some preliminary suggestions for a stereoscopic spotting trainer have been advanced. (148) Spotting with the range finder is primarily a Navy requirement. The suggested trainer is a device for simulating an aerial target within the reticle field of a stereoscopic range finder. The presence of shell bursts is represented by white or colored lights which appear at various desired ranges, elevations, and azimuths within the stereoscopic space. Tracking errors are simulated by providing that the target and shell bursts execute irregular vertical and lateral movements during the course of all observations. Detailed plans of construction are given.

14.2.2 The Training Program

Most of the training program is to be found in the Service manuals and is the result of many years of Service experience. Much, however, has been the result of work at the Fort Monroe Princeton Laboratory, and some has been contributed by laboratory studies elsewhere, although this has not been the primary purpose of these latter investigations except in the case of the studies at the Fire Control School at Fort Lauderdale.

The Howe Laboratory, investigating the amount of practice advisable in ranging on a simulated high speed diving target (310) they found that at least 180 aerial courses or their equivalent was a reasonably safe minimum. This finding is the result of training 11 observers on the instrument described above. It was found that improvement in continuous contact performance significant at the 1 per cent level was observed after an average of 165 courses had been ranged. Improvement in make-and-break contact performance was observed after an average of 141 courses were ranged by each subject.

At Tufts College a study was made of the effect of knowledge of results on training of ranging a moving target. (563) The method used was an automatic buzzer signal sounding whenever the subject's error in ranging became greater than ± 5 or ± 2.5 UOE. The subject, with this knowledge, was instructed to try to do so well that he would keep the buzzer from sounding. The results indicate that the type of knowledge training reduced both constant error and variability in ranging. These results emphasize the importance of immediate knowledge of results of the ranging during operator training and also the importance of a training instrument with a true zero. Both of these factors are incorporated in the Eastman M4 Trainer and both are lacking in the older M2 Stereoscopic Trainer.

Relative Effectiveness of 3 Training Instruments

An intensive study of the relative effectiveness of the M1 Height Finder, the M2 Trainer and the Eastman M4 Trainer in the training of stereoscopic height finder observers was made by the Princeton Laboratory at Fort Monroe. (360) The subjects consisted of 36 students in a class at the Height Finder School. They were chosen from a group previously selected at Fort Eustis by the selection tests discussed above. Three groups of 12 men each were famed for training. The first 2 weeks of the course were devoted to training in theory, care, and operation of the height finder for all three groups of subjects. The remaining 10 weeks were devoted primarily to training in stereoscopic observations. During this period Group A practiced the full 10 weeks on the M1 Height Finder. Group B practiced several weeks on the modified M2 Trainer and spent the last 3 weeks on the M1 Height Finder. Group C spent the first 7 weeks on the Eastman Trainer and the last 3 weeks on the M1 Height Finder.

All three groups participated in three special tests on the height finder reading on both fixed and aerial targets. The first test came at the end of the fourth week when each man read 12 fixed target courses, 8 aerial height courses and 7 or 8 aerial range courses. The second test came at the end of 7 weeks when each man read 10 fixed target courses and three aerial height courses. The final test, at the end of 10 weeks, required each man to read 8 fixed target and 8 aerial courses. All three groups received the same training throughout in theory, care, and operation of the height finder, in keeping and computing records, in tracking and recording on the height finder, and in

all other aspects of training except that from the second through the seventh week Groups B and C made no stereoscopic observation with the height finder. All measurements were made in precision error score, which was currently in use by the school.

The results indicated that men can be trained effectively as stereoscopic observers on either the modified M2 Trainer or the Eastman Trainer. Students require about 125 courses on either training instruments or the height finder, at least 25 of which are on the height finder, to become proficient observers.

The recommendations of this report were adopted and put into effect by the Army. Something over 6 months' experience utilizing the newer training methods, with emphasis on the use of the training instruments in the early stages are reported. (368) This report is based upon the work of four successive classes at the Stereoscopic Observers' Course at Fort Monroe and at Camp Davis and indicates the experience of training 134 men.

Objectives of Course

The course had the following objectives: (1) To teach the student how to make the preliminary adjustments required on a height finder, such as focusing the eyepieces, setting the interpupillary distance, and checking the height of the image. Training instruments are excellent for this purpose. (2) To give the student practice in using a binocular instrument. In this connection the training instruments proved excellent in overcoming the confusion resulting from an inability to obtain fusion of the images of the two eyes. (3) To give the student practice in making stereoscopic contact. The student was taught how to use the instrument, with emphasis on bracketing methods, the use of the fine elevation control, and reading when faced by a time interval device. The student practiced using both broken and continuous contact. The training instruments were adequate for simulating different types of courses on which the rate of change of height and range may be slow or fast. The relative advantage of using broken or continuous contact for each type of course could, therefore, be explained. (4) To give the student practice in computing records and in keeping a record book. This can be done as adequately with trainer data as with actual range finder data and such computations may also form the basis for the determination of calibration corrections. (5) To give the student an understanding of the measures of performance which he computes. Hence it is possible to explain the relative importance of the various measures from the standpoint of data transmission, director performance and damage to airplanes. The advantage of taking frequent readings can be demonstrated and the student can be warned of the importance of target contrast, the inadvisability of changing from one target position (below the reticles) to another (above the reticles) after a calibration correction has been established. All of this may be adequately accomplished with the training instruments.

This preliminary period of work with the trainers should be followed by intensive experience with the range finders themselves. The objectives of this second part of the course are as follows: (1) To instruct the student in the duties of all the positions associated with the operation of the range finder, such as trackers and data transmitters. The student is also instructed in the maintenance of the instrument and in the necessary care in carrying, setting up, taking down, storing, and transporting the range finder. It was found that it was particularly important to have drills in the removal of electrical and mechanical connections between the parts of the instrument when dismounting the range finder; how often to clean, oil, paint, and recharge the instrument; and how frequently he must check the wedge and height adjustments. (2) To emphasize again the importance of the preliminary adjustments so that the instrument may be left in a condition ready for action. (3) To develop the student's reading skills acquired during the trainer practice. With the change to the actual range finder, the student learns the feel of the range knob, the necessary changes of body and head position as the instrument moves with the tracking of an aerial target, and the changing aspect of the target itself. The use of 12 and 24 power magnification is taught at this time. (4) To continue the lessons on computations and calibration corrections. Emphasis was again placed on the importance of a stable calibration correction. Since this depends upon care in setting the interpupillary distance, proper maintenance of helium content, the use of diaphragms and sunshades, and frequent checks of wedge and height adjustments, these phases of the work were taught at this time. (5) To instruct the students in the place of the height finder in the gun battery and in the tactics of the battery. In this connection, the problems of transmitting the data to the

director and orientation and synchronization were treated. The lesson on tactics also included such problems as the range within which firing is effective, night reading, camouflaging, sandbagging the instrument, and the protection and decontamination of the instrument during a gas attack. (6) Identification of about 90 of the commonly used friendly and hostile aircraft, and knowledge of the tactical employment of each type and the theatres of war in which each may be encountered form a part of the course.

The experience with the 134 men of the four classes of the Height Finder School demonstrated that all of these objectives may be attained in a course of 12 weeks duration. During the first half the students practiced entirely on the M2 and the Eastman M4 Trainers. In the second half, the students worked with the actual height finders. Hence the efficiency of a school with a given number of height finders may be doubled by this procedure.

Tables and charts are given which indicate that the learning limits with the trainers are reached within the designated time limit. The number of courses required to reach these limits, both fixed and moving, is also indicated, as is the final level of performance expressed in UOE.

There is appended to this report (368) a detailed program extending over the 12 weeks period with the work for each morning and afternoon designated for each day. This course allows the student to have regular contact with the height finder, even during the training period, and arranges that the lectures on theory and records be closely coordinated with the practical work. Suggestions are made in the schedule arrangement to relieve the monotony of the course as much as possible. Suggestion is also made that with the elimination of some of the instruction on the theory of the optics of the instrument and less emphasis on drill, this proposed 12 weeks' course could possibly be reduced to 9 or 10 weeks. In regard to final grades, it is emphasized that accuracy of reading is the essential measurement of performance in actual height finder performance in the field and the recommendation was made that the final grade be made on an accuracy basis. A number of cautions are given if such a final criterion should be adopted. The Fire Control Division of NDRC recommended the adoption of these suggestions. (24)

Training Manual

As a result of these recommendations, a training manual for stereoscopic height finder observers was prepared under the direction of the Committee on Service Personnel — Selection and Training of the National Research Council, and carries their recommendation for adoption. With certain changes, largely verbal in character, this manual was adopted by the Antiaircraft Command. The proposed manual was issued in three parts. (68, 70, and 71)

The manual contains much more material than the training program outlined above. One will find therein the incorporation of many of the suggestions which have grown out of the research, both at Fort Monroe and the several laboratories, ranging all the way from maintaining a helium charge on the instrument to methods of focusing the eyepieces. Much of this material will be found outlined elsewhere in this summary. A 12 weeks' course of study is contemplated and the manual is to be used as the basic text of such a course. Day to day references in the manual are indicated for study during the training period. The manual is fully illustrated.

Inasmuch as this manual, in a sense, summarizes much of this work, a detailed description would seem of value. The first chapter (11 pages) outlines the function of an antiaircraft battery of 90 mm guns. The antiaircraft firing problem is described and the function and importance of the height finder in the battery is discussed. The second chapter (11 pages) explains very simply how angles, ranges, and heights are measured and indicates how this is done with the optical range and height finder. The third chapter (14 pages) which describes the various optical elements and indicates what effect each has upon a light ray falling upon or transmitted through it. In a fourth chapter (9 pages) the principle of the stereoscopic range finder is outlined and the fifth chapter (15 pages) indicates, in simple language and with many illustrations, how this is accomplished in this particular stereoscopic instrument. Chapter 6 (30 pages) describes the M1 Height Finder in detail, both with regard to its optical system and other parts. Here the student becomes acquainted with the technical terminology of the instrument. The seventh chapter (4 pages) concludes the first part of the manual on the theory and construction of the height finder and briefly outlines how this instrument works.

Part II of the manual deals with the operation of the height finder. Chapter 8 (14 pages) explains how the instrument is set up, leveled, oriented, and synchronized, and corrected for vertical parallax. Chapter 9 (12 pages) describes the preliminary adjustments such as interpupillary setting, selection of

power and filter, focus, height of image, internal adjustment and setting of height range lever. This is followed by Chapter 10 (16 pages) which is solely concerned with a more detailed description of the internal adjuster system and its operation. Both methods of calibration on heavenly bodies, and the use of the internal adjuster scale are described. Chapter 11 (15 pages) lists the duties of the different members of the height finder crew and describes the way the stereoscopic observer should operate the instrument when reading ranges and heights. This chapter treats of such topics as the importance of smooth tracking, placing of the target with regard to the reticle, broken and continuous contact methods. The second part closes with Chapter 12 (3 pages) in which are described the rules and methods for dismantling and packing the height finder.

In the third part the important problems of calibration and record keeping are developed. Chapter 13 (15 pages) emphasizes the need for accurate height finder readings and contrasts the concepts of accuracy and variability. At this point the importance of these factors for the director is emphasized. Chapter 14 (7 pages) has to do with the two methods of obtaining a calibration correction; while Chapter 15 (3 pages) is an introduction of record keeping of both daily height finder records and the maintenance and of the instrument. The 16th chapter (9 pages) outlines the arithmetic and the meaning of the statistical terms necessary for such record keeping. Chapter 17 (5 pages) is an introduction to scale reading and describes the kinds of scales found on the M1 Height Finder. Chapter 18 (9 pages) describes the methods of changing height finder errors measured in yards into units of error. Chapter 19 (13 pages) of this part of the manual, describes record forms and how they should be kept.

The fourth part of the manual is concerned with the maintenance of the height finder. Chapter 20 (11 pages) contains general directions for maintenance. Chapter 21 (20 pages) gives detailed instructions for desiccation of the instrument, for charging it with helium, and for subsequent testing for helium purity. Both the helium purity indicator and the Oliver methods of helium charging and checking are described. The 22nd Chapter (16 pages) is concerned with the optical and mechanical adjustment of the instrument. Such items as wedge check and tracking telescope collimation, and the main bearing race backlash test and end window adjustment tests are considered. Chapter 23 (9 pages) outlines the assembly, operation, and maintenance of the M2 Height Finder indicating the differences between this and the M1 instrument. In Chapter 24 (3 pages) are given forms and detailed instructions for maintenance records.

The fifth part of the manual deals with the use of the height finder in the field. Chapter 25 (4 pages) has to do with transportation and storage. Chapter 26 (4 pages) describes how the instrument should be emplaced. In Chapter 27 (5 pages) simple rules are given for obtaining calibration corrections in the field. In Chapter 28 (10 pages) are described accessories which improve height finder operation, such as the use of end window stops, sun shade and cover, and the optical gas mask M1-1-5. Chapter 29 (3 pages) tells how to order replacement parts for the height finder. "A Gun Battery in Action" is the title of Chapter 30 (7 pages) and here are detailed such matters as communications, commands in action, the need for speed, height finder readings and data transmission and horizontal fire at non-aerial targets. Chapter 31 (2 pages) gives simple rules for the care of the eyes of the range finder operator. Chapter 32 (3 pages) gives in tabulated form a summary of height finder errors and how to avoid them.

The sixth and final part of the manual is entitled "Instructor's Section". Chapter 33 (14 pages) is an outline of the methods for selection of height finder observers for use both in Stereoscopic Selection Centers and by battery commanders in the field. Chapter 34 (18 pages) describes such training instruments as the M2 Trainer (both modified and unmodified) and the M6 Trainer and M7 Trainer with suggestions for their use in a training course. Chapter 35 (7 pages) presents a suggested schedule for a 12 weeks' course for stereoscopic observers in which detailed outlines are given for day to day instruction during the first 6 weeks. Chapter 36 (7 pages) makes teaching recommendations. In the final chapter, 37 (3 pages) will be found a list of references of Service manuals and instructional films within this general area.

This manual is extremely well written and is in exceedingly simple and clear form so that it should be readily understood by any soldier with sufficient intelligence to pass the selection tests for a stereoscopic range finder observer. The many illustrations are excellently selected and greatly aid the understanding of the text. One cannot but help be impressed with the inclusive manner in which this field has been covered and with the fact that so many of the suggestions which had grown out of the research

of the several previous years are included in the discussion.

14.2.3 Characteristics of Learning Curve

The Applied Psychology Panel has reported a further study of learning curves for operators of stereoscopic range finders, particularly as these apply to the Naval situation. (100) This is a study of the characteristics of learning during the last 8 weeks of range finder operation in the 16 week course of training for fire controlmen (0) at the Naval Training Schools, Fort Lauderdale, Florida. Prior to the final 8 weeks of training on the range finder with moving targets, 8 weeks were spent on stereoscopic trainers and concurrent with the last 4 weeks on these trainers, practice was given on range finders with fixed targets. This investigation is a practical study of the progress of learning under training school conditions and was designed to answer practical curricular problems of how much practice may be profitably spent in various types of drill.

The data for two classes are analyzed separately to afford comparisons. The criterion of range finder proficiency used is the scatter score, which is a measure of the variability of the operator's range errors determined from "true" or reference ranges obtained by means of radar equipment with experienced operators.

The results of the study indicate that for moving surface targets no statistically significant improvement can be demonstrated after the first half (2 weeks) of the practice periods now in the school curriculum. This holds true for both classes. For aerial targets, the learning curve for one class shows statistically significant improvement up to the final week; for the other class no significant improvement can be shown after the half-way point in the practice periods has been reached. In general, it may be said that the learning curves of performance on the range finder indicate that the maximum levels of proficiency demonstrated were usually reached considerably before the completion of the time allotted to practice on both types of targets. It is suggested that, for aerial targets, one of the most important causes for the apparent absence of improvement after 2 to 3 weeks of the 4-week period had elapsed was the relatively easy course flown by the target and another was the loss of interest or motivation resulting from knowledge that graduation standing and assignment had already been determined.

It is impossible to designate an arbitrary score as the dividing line between satisfactory and unsatisfactory range finder performance since insufficient information is available concerning the range errors the Mark 1 Computer will tolerate. It is necessary, therefore, to hold as a training goal the maximum proficiency that can be obtained and, if terminal plateaus on the learning curve do occur under modified conditions of training, the resulting over-learning would be of definite value in reducing variability of the optimal proficiency of the operators.

14.2.4 Recommendations

On the basis of these results and other empirical evidence discussed, the report recommends: (1) that the 4 weeks of practice with the moving surface targets be reduced to 2 weeks; (2) since the above recommendation provides 2 additional weeks, the present 4 weeks devoted to aerial targets be increased to 6 weeks; (3) the aerial courses flown by the target plane be made progressively more difficult throughout this 6 week practice period; (4) the motivational devices now being used be continued and that the possibility of using other incentives during work on stationary, moving surface, and aerial targets be seriously investigated and adopted when practical.

A British report gives in great detail their early experiences in the training of stereoscopic range finder operators. (303) In this report are included learning curves of men who had had no previous experience in ranging and of men who had had a very great deal of previous experience as range takers but with coincidence type of instruments employed in the British Navy. This latter group did less well possibly because of greater age or possibly because of prejudice against the stereoscopic type of instrument.

A general final report of the work of the project under the Applied Psychology Panel will be found in a single publication which summarizes the results for both training and selection of stereoscopic height finder operators. (90)

As aids in the training program two simple devices are suggested for use in height and range finder training establishments. The first deals with the design, accuracy, construction, and use of a range correction computer and is reported by the Applied Psychology Panel. (81) In training operators of range finding in-

struments it is necessary to have some means of measuring the precision of their operation. To do this, one must know the true range to the target upon which the student operators are ranging. Assuming that an accurate series of ranges can be obtained from a nearby point, the problem of correcting for disparity in space between a number of range finding instruments and the point from which the range is known still remains. The computational labor involved in making these corrections to a number of instrument stations can be largely eliminated by the use of a computer which, given the true range and the azimuth angle of the target from one point, provides immediately and simultaneously the true ranges for all stations lying on an approximately straight line. The present memorandum describes the construction of such an instrument and gives instructions for its use.

The design, accuracy, construction, and use of a range finder slide rule is reported by the Applied Psychology Panel. (86) The accuracy and precision of range readings obtained by students with stereoscopic range finders at the Naval Training School at Fort Lauderdale, Florida, were measured in terms of median error and scatter score respectively. The computation of these scores by longhand methods is laborious and lengthy. For such scores to be of practical value for training and grading purposes, the time and labor of their computation must be held at a minimum. Use of the DeYoe slide rule permits the computation time of these scores to be reduced by approximately one-third, but the procedure is still tedious. The range finder slide rule described in this report was found to be more accurate and more convenient to use than either a longhand or DeYoe method of computing range error scores. The new instrument makes possible a procedure for the computation of the median error and scatter scores which requires approximately only one-fifth the time of the longhand method and one-third the time of the DeYoe method. Its use is recommended for adoption by the Services. The new slide rule is described and instructions for its use are given in the report.

As an aid in the training program, the British report the development of two computing instruments for the easy determination of the skill of an optical range finder operator. (61) One instrument determines the summation of the errors or bias of the operator, the other determines the scatter of the instruments. The report does not describe either computing device in detail.

Operators of optical instruments and of oscilloscopes in both Services have in many cases felt that their work has an injurious effect upon visual functions. This led to an investigation of the effect of a 16 weeks course upon visual functions at the Naval Training Schools at Fort Lauderdale reported by the applied Psychology Panel of NDRC. (96) This course requires a large number of hours of practice on stereoscopic trainers and range finders, on tracking telescopes and on radar oscilloscopes, in addition to reading for theory courses. Measures of visual acuity (far and near vision), vertical phoria, lateral phoria, stereopsis, and color vision were obtained with the Bausch and Lomb Ortho-Rater and an additional measure of stereopsis was obtained by the Stereo Vertical Test with the Multiple Projection Eikonometer. These measures were obtained for an entire class of some 75 men at the beginning and again at the end of the 16 weeks course.

It was found that: (1) there was no deterioration of any of the above visual functions as a result of this practice experience; (2) there was a slight improvement in visual acuity scores for the dominant and non-dominant eye; (3) there was an improvement in stereopsis score on both tests with the two different instruments; (4) There is an improvement in color vision score. On the basis of these findings it is recommended that all Service personnel who are required to use their eyes in operations similar to range finding or oscilloscope operation, be indoctrinated with the knowledge that it is much more probable that their visual functions will improve than that they will deteriorate. It should be remembered that under conditions of stress or persistent emotional maladjustment men may complain about their eyes even when thorough medical examination shows no obvious physical basis for the complaint.

PART IV

NEW DEVELOPMENTS OF RANGE FINDERS

THE PRECEDING chapters have to do largely with existing range finder instruments, their construction, the control of errors which may occur in them, and their operation. Many of the recommendations have been recognized as a mere reduction of the effects of certain errors rather than their elimination. The introduction of helium as a charging gas to alleviate the effects of temperature stratification is an excellent case in point. Certain fundamental studies were attempted to produce new instruments and these experiments and designs are summarized in the last three chapters (Chapters 15 to 17).

Chapter 15 deals with the development of certain short base range finders—first for the control of lower caliber antiaircraft weapons and subsequently for use in tanks and other armored vehicles against usually obscure ground targets. Comparative tests were made for this latter problem and various types of range finder fields were tried. This led to the recommendation of a coincidence type instrument because it was immediately available. Further development of a stereoscopic instrument with projected illuminated reticle was also strongly recommended.

Chapter 16 reports a series of systematic studies of reticle design which resulted in the determination of a set of fundamental principles underlying such design. Two problems seem to be of importance in the selection of reticle pattern—avoiding false fusion and eliminating the effects of the height-break error. Although fore and aft marks do not prove to be of value for ranging consistency or precision, the retention of a very simplified set of such marks may give very valuable cues of false fusion. The lengthening of the fiducial lines aids in counteracting the height-break error.

In Chapter 17 work is indicated in the design of new instruments, which is still being carried on, and by which it is hoped that many of the sources of error, found in existing instruments and controlled in various ways, may be entirely eliminated by design and by the introduction of newly devised optical parts and their mountings.

Chapter 15

DEVELOPMENT OF SHORT-BASE RANGE FINDERS AND THEIR APPLICATION TO GROUND AND AERIAL TARGETS

15.1 THE SHORT BASE RANGE FINDER

EARLY IN the NDRC contact with fire control problems, it became evident that short-base range finders could have a number of extremely important applications. For such applications, extremely great precision was not required. With the development of automatic weapons for anti-aircraft fire, for example, it became of importance to know when to open fire. Hence it was envisaged that a range finder might be developed which could be set to the desired range and firing held until the target was within this range. A similar application was thought of for plane to plane fire control. Later an application for armored vehicles required the determination of the exact range of the target. There are also many infantry applications desirable for rifle and machine gun fire and for motor and rocket projectile. Hence the Eastman Kodak Company and the Polaroid Company were asked to develop range finders for these applications. This development was to provide an instrument for short and intermediate ranges. Emphasis was upon ease of construction and operation. A historical statement and projected uses of the instrument will be found in Fire Control Division Report to the Services. (6)

The Polaroid Corporation had already developed, under encouragement of the Bureau of Ordnance, Navy Department, a simple instrument, the Mark 1 range finding sight. This is described in a report. (341) It is a combination sight and stereoscopic range finder of unit power. It has no viewing lens system whatever and consists of four mirrors combined with a new type of collimated sight. Ranging was accomplished against a projected fixed scale and this was deemed less desirable than an instrument of the Wandermark type. This instrument had a 27-inch base length and a calculated mean accuracy of 67 yards at 1,000 yards.

In response to the Section's request, Polaroid Corporation suggested a number of ways in which existing binoculars could be converted to range finders by means of simple attachments. One of these, selected on the basis of ease of manufacture and use, was developed by the company. This is described in a report. (342) It uses the principle of superimposed coincidence; that is, it produces within the same field two images of the target overlying one another but displaced by an amount proportional to the parallax of the target as seen from the two ends of the attachment. By rotating the ranging wedges, these two images move laterally and are accurately superimposed for that position of the wedges which corresponds to target distance. Although this instrument had a base length of only 6 inches and a theoretical computed performance of 38 yards at 1,000 yards when 8-power magnification was supplied, it was not further developed. Instead the Polaroid Corporation developed a 43-inch stereoscopic instrument with a projected Wandermark type of reticle.

Meanwhile the Eastman Kodak Company also produced an instrument of the superimposed coincidence type, which is completely described. (196) Basically this instrument is of conventional design, but two important modifications were introduced. One is the use of complementary color filters in the two light paths, so that red and green images of the target are produced. These superimpose and fuse into an image of normal color for that position of the ranging mechanism (in this case, a moveable mirror) which corresponds to the target distance. The other modification is the introduction of a novel but simple method by which the instrument is rendered auto-collomating. The introduction of such a device is necessary because the optics in range finders are subject to minor derangements due to temperature changes and other causes which, if uncorrected, would cause errors in range readings. Ordinarily, such instruments are provided with a range corrector or internal adjuster, by means of which the infinity setting of the scale may be checked and adjusted. When an instrument is so constructed that the reading of the range scale is not affected by these minor derangements, and no internal adjuster is required, it is said to be "auto-collimating". In the Eastman instrument it was necessary only to place a line in the gate between two diamonds to make this correction. This instrument has a base length of 15 inches, is supplied with 6-power and has a calculated accuracy of 20 yards at 1,000 yards.

15.1.1 Tests of Instruments and Operators

Inasmuch as the usefulness of instruments of this type would be much reduced if it was necessary to select as operators men with special abilities and then to give them a considerable training, a field test with unselected Army personnel was made. This is reported in a Report to the Services issued by the Field Control Division of NDRC. (23) The tests were made at the side of B Battery 602nd CA (AA) in the vicinity of New York. It was hoped that two questions might be answered: (1) can ordinary soldiers use instruments of this type and (2) what accuracy may be expected from their use.

In this study a total of 5,602 ranges on 8 targets at ranges between 209 and 1,813 yards were made by 10 trained stereoscopic observers and by 13 untrained and unselected men picked at haphazard from the Battery personnel. None of this second group had previously looked through a range finder of any sort. Some of the targets favored the coincidence type of instrument, e.g., a flagpole at 1,388 yards. Others favored the stereoscopic type of instrument, e.g., a concrete abutment in shadow under a bridge at 618 yards. Some targets had a sky background while others did not. Both instruments were held by hand throughout the tests.

An analysis of the results indicated that, using 10 per cent accuracy as a criterion, six of the eight trained observers were able to use the 15-inch Eastman instrument satisfactorily to at least 600 yards, whereas six of the eight obtained satisfactory readings to at least 1,800 yards with the Polaroid instrument. It will be remembered that these observers had been previously selected and trained in stereoscopic range finding. The other two observers, though similarly selected and trained in stereoscopic, could not obtain satisfactory ranges by this criterion beyond 200 yards with the Polaroid 43-inch and one could not use it at all. On the Eastman instrument, the two men who failed to meet the criterion at 600 yards met it at 400.

Among the untrained group, seven of the thirteen men used the Eastman instrument satisfactorily to at least 600 yards, while five of the thirteen used the Polaroid instrument satisfactorily to at least 600 yards. Six of these men could not use the Polaroid beyond the same range. In other words, only half of the untrained group could use either instrument and the performance of those who could was about the same on both instruments. In the hands of the untrained groups the Eastman 15-inch instrument gave better results on distant targets (beyond 1,000 yards) than the 43-inch Polaroid instrument. For the trained group this situation was reversed — but against it must be remembered that these men had had previous stereoscopic training, particularly on targets at long range.

It was discovered that bad ground background reduces the accuracy of both instruments in a fairly predictable way as compared with ranges against targets with a sky background. Also, after the first half day's indoctrination, the untrained group showed no appreciable increase in accuracy with either instrument, though over 150 additional ranges were taken. However it was observed that there was a marked increase in the speed of making range observations during this additional period of practice. At the close of the test, the observers were asked to estimate the range to each of the targets without the aid of instruments.

As a result of this field test, the following conclusions were drawn in regard to the Eastman 15-inch and the Polaroid 43-inch range finders:

1. Either instrument, even in the hands of untrained observers, gives results which are considerably better than unaided range estimates.
2. Neither instrument can be handed out indiscriminately like a mess kit. Some sort of selection and training of personnel is required.
3. Selection of observers could consist merely of trying out on the instrument itself at least twice the number of men required for observers and replacements.
4. The selected personnel should be given three or four days' training in which, in the earlier stages, emphasis should be on increasing accuracy and, in the later stages, on increasing the speed of range settings.
5. If this procedure is followed, either instrument can be expected to have a useful range of 600 - 800 yards.
6. By careful selection and training, the useful range of the Polaroid instrument can be extended to at least 2,000 yards. What could be accomplished by careful selection and training with the Eastman instrument is unknown. It is anticipated, however, that the 8-power 30-inch Eastman instrument now under construction will have a useful range of at least 1500 yards.

Similar examination and tests were made by the

British Admiralty Research Laboratory for both the Eastman (48) and Polaroid (49) instruments with approximately similar results. As a result of these field tests the Polaroid Corporation made certain modifications in their instrument but these were never reported and eventually the project was dropped.

Meanwhile the Eastman Kodak Company developed this same idea into a 30-inch range finder which was accepted by the Army as M10 for use with the M5A2 Director. Description of the 15-inch instrument and instructions for its use are contained in a report (208) which also gives schematics of the optical system employed.

The Eastman Kodak Compay has also reported a series of tests made with the 15-inch instrument. (199) The ranges employed varied from 102 to 2,058 yards. The data include 217 groups of 5 readings each. The average spread (the difference between the highest and lowest reading) for these data was 4.4 UOE. Some targets appeared to be slightly better than others from the point of view of precision. A high contrast target at 102 yards gave an average spread of only 2.6 UOE while a chimney at 457 yards gave an average spread of 5.4 UOE. In regard to accuracy it was found that most of the readings fell within the limits of plus or minus 5 UOE. However, if five ranges are taken and the results averaged, the average value will vary from true range by more than 5 UOE only in two or three per cent of the cases for fixed targets. Suggestions for improvement of the instrument are outlined on the basis of this experience.

The Eastman Kodak Company has reported the description and operating instructions of two 1-meter range finders developed for infantry use and designated as T-25 and T-26. (206) The T-25 is a full-field superimposed-image type having two nearly identical images of different colors. The T-26 is of the split-field invert-coincidence type. Both instruments have an interior semi-auto-collimating range corrector system which may be set at any time by observing the interval range scale. The two instruments are identical in optical and mechanical details except for the center coincidence prism assembly and its mounting frame. By interchanging eyepieces, the power of the instruments may be changed from 11.5x to 15x. Calculated acuity is 2.5 UOE or 30 seconds of arc at the eye. At 1,000 yards this should give an average error of 11.6 yards with 11.5 magnification, and of 8.9 yards with 15 magnification. The instruments have a field angle of 4 degrees. The range scale is read by a second observer. These instruments were tested at Fort Benning by the Infantry Board.

A 1-meter ortho-pseudo type range finder was designed by the Eastman Kodak Company. (211) A description and schematic drawings are reported. The computations indicated that it would have a 15x magnification and a 3-degree field and would be useful out to 3,000 yards. No layout drawings were ever made and the project was dropped.

There is a British report of trials with a fixed scale. 1¼-meter base Levallois Stereoscopic Range Finder for antiaircraft use. (52) From a light AA Battery, 117 men were given one day's training in the use of the instrument and a check was taken at the end of the day of their ability to take ranges on an aircraft flying on a straight course from 5,000 meters through a crossing point at approximately 1,000 meters at a height of approximately 2,000 feet and a speed of 150-200 mph. Of this practically unselected group, 15 per cent produced excellent results (less than 200 seconds of arc error), and an additional 18 per cent produced reasonably good results (200-400 seconds of arc error). Firing trials using the Levallois instrument, in conjunction with a predicator-controlled Bofors gun, demonstrated that with range finder cooperation the percentages of hits in the total number of rounds fired and in the line of sight rounds, are both markedly higher than the averages obtained when employing the normal drill (13.6 per cent or 24 per cent hits in line of sight rounds as against 7 per cent average of 2 months of practice camp firing).

15.1.2 Application to Armored Vehicle Use

It became evident during the progress of the war that the usual artillery methods of range estimation and a bracketing procedure were too slow and used too much of the limited available supply of ammunition to be completely acceptable for use by armored vehicles. A British report tells of a firing trial using the Barr & Stroud No. 12 (80 cm base, magnification 14) against range estimation without the use of instruments. (54) A bracketing procedure was employed in both cases, but, for visual range estimation, the opening bracket was one complete turn of the handwheel (25 mils) while only 1/4 turn was used in the range finder experiments. A different tar-

get was engaged each day—the ranges varying from 815 to 2,723 yards. In all 20 tank crews were tested.

The use of the range finder combined with the type of fire control described resulted in a saving of ammunition. It was estimated from the results of the trial that the use of the range finder saved 1½ rounds of ammunition per engagement. This conclusion is based on firing at ranges up to about 2,000 yards with two longer ranges excluded. It was also found that the use of the range finder will increase the chance of a hit with the first round by about 100 per cent. This conclusion is based on the results of the firing at all the ranges employed. The range finder was mounted on a bracket on top of Sherman (M4A4) Tanks and it was found that the adjustment of the instrument was unaffected by gunshock by fire of 75 mm guns. The range finders were operated by the tank commanders, who were trained in its use for 2 hours per day for 7 days. This amount of training gave a completely satisfactory standard of operation. Hence this report recommends the range finder as a useful fire control instrument for tank gunnery and advocates that it should be issued to tank units.

An analysis of the actual numbers emphasizes the validity of these conclusions. In one set of trials with eleven targets varying in range from 955 to 3,785 yards, the average error for visual estimation was 575 yards, against the average error with the range finder of only 75 yards. In the case of no single target is the average of visual estimation better than the error with the instrument. In the case of only two long range targets is the average instrumental error more than 100 yards and even this is more than five times better than the average for estimation for these same two targets. In another set of trials the averages for six targets (from 815 to 2,723 yards) gave average errors for visual estimation of 374 yards and for the range finder of 67 yards. For still another set of trials for 14 targets ranging from 428 yards to 5,300 yards, the average errors for visual estimation are 598 yards and for range finder 168 yards. In these last results, if the two extreme targets, which are probably beyond the usable range of the instrument, are eliminated (4,810 and 5,300 yards) the average errors are 428 yards for visual estimation and 87 yards for the range finder. A statistical analysis of these results indicates that the average error of visual estimation of range is approximately a linear function of range and is approximately 30 per cent of the range at all ranges from 800 to 4,000 yards, and that the average error of range finder estimation is a square law function of range and is approximately $20r^2$ (where r is the range in thousands of yards). At the ranges considered in this report this is approximately 2 to 6 per cent of the range.

A further British report describes trials with the Barr and Stroud Range Finder No. 2 as compared with the Infantry Range Finder No. 12 in application to the armored vehicle problem. (545) Tests were made of accuracy and speed in fair to good conditions, using eight targets and eight range takers. Subsequent tests were made in poor light; the targets were all ground targets at ranges varying from 935 to 5,200 yards. Both range finders were mounted on their usual tripod mountings. All observers were trained in range finding technique. The results showed that the error in ranging was almost exactly inversely proportional to the base lengths of the instruments (80 cm and 100 cm respectively) and also that both instruments are almost equal in speed of use. It was determined that both instruments were equally affected by fading light, giving full accuracy until about 10 minutes before the target can no longer be seen. There was no measurable correlation between the visibility of the target as measured with a Casella visibility meter, and the accuracy with which its range can be determined, though some targets give less accurate readings than others, probably because of their shape. The accuracy of the instruments is discussed in relation to the other errors in tank gunnery. The conclusion is reached that the 100 cm base instrument offers no appreciable advantage if the accuracy measured in this trial is attained on the battle field; if, as seems probable, ranges measured in battle are substantially less accurate, this conclusion may be incorrect. The average time for making coincidence settings was approximately 25 seconds.

Another British report indicates the large errors found in visual range estimation. (340) Results were taken both for estimation of opening range and for fall of shot for correction of range. The results show that in estimating range, the longer the range the greater the error in estimation. The average error, without regard to size, rises from 250 to 375 yards between ranges of 900 to 2,000 yards, and increases rapidly at ranges over 2,000 yards up to 1,000 yards error at 2,650 yards. In estimating range correction, the larger the correction to be made, the greater the

error in estimating it. The use of a sighting telescope (powers 2x to 6x) instead of the unaided eye did not reduce the errors in estimation of range correction whatever the magnification employed. In both estimation of opening range and for range corrections there is a tendency to underestimate long ranges and larger corrections.

In another British report the use of a range finder for tank gunnery with immediate fire for effect is recommended. (339) It is calculated that in order to obtain a minimum standard of one hit in three during fire for effect at a target 6 feet high and 9 feet wide at 2,000 yards with a 6-pounder gun, a range finder with either no systematic error and a dispersion of observations not exceeding $10r^2$ (where r is range in thousands of yards) or a systematic error of 12 yards and no dispersion of observations would be required. Mention is also made that trained tank gunnery instructors are not significantly better in visual estimation of range than people with no gunnery training or experience.

Finally, the British report an experiment to determine the suitability of the No. 12 Infantry Range Finder (80 cms, 14x magnification) for tank use. (53) For this experiment, three instruments were used, two mounted on tanks. There were four observers ranging from untrained to fully trained men. The targets consisted of hull down tanks, mock-up anti-tank guns, a hut, and a factory chimney varying from 668 to 3,784 yards true range. There were six targets in all. The range finders stood up well to the vibration of a tank in motion. There was no firing. The results indicate that for any one target, an average observer may be expected to have a systematic error of $\pm 10r^2$ yards and a mean deviation of $15r^2$ yards where r is the range in thousands of yards. It was recommended that three readings be taken on a target and the median of the three readings be used as the range for opening fire. The results indicate that even a single range reading gives a satisfactory value of the range to be determined, but it is felt that the increase in time, probably about 10 seconds, which is required to obtain two more readings, would be well spent in eliminating the possibility of the gun being set to a value determined from a hasty, and possibly, erratic, single reading.

From an analysis of the readings of the individual observers, it is evident that the two trained observers were much more consistent than either the semi-trained or the untrained observer, to a degree of almost 50 per cent. All three instruments were found to be extremely stable over a temperature range of 42 to 70 degrees Fahrenheit; in no case did the readings change more than 3 seconds of arc.

Studies on Range Estimation

A similar comparison between visual range estimation and the use of range finders was made at Fort Knox by the Bausch and Lomb Company. The range estimation tests are reported along with range finder tests. (110) Through the cooperation of the Gunnery School at Fort Knox, data were made available on the performance of classes in range estimation without instrumental aid before and after training. The group were taken to the site for the range finder experiments and estimated the range to several of the designated targets without being told the true ranges. They were given training once a week for 7 weeks in range estimations on entirely different terrain and then were brought back to the original site. These results indicate a marked superiority of a series of trained estimates over untrained ones. However, these experiments agree with the British findings that no amount of training will give an average accuracy of visual range estimate better than 15 to 17 per cent of true range. There is some evidence that even such accuracy cannot be maintained without constant and continual practice. And even with highly trained observers, individual estimates will frequently be made very far from true range. Furthermore, there will be a tendency for these errors to increase when a unit proceeds to new terrain and/or encounters new or unfamiliar weather conditions.

These same range estimation results by 60 officers before and after training were given further statistical analysis by the Princeton Branch of the Frankford Arsenal. (244) They find that the percentage error in range estimate is independent of true range both before and after instruction. The probable error for this group before instruction was 30 per cent of true range and after instruction this was reduced to 17 per cent of true range. The percentage of error was found to vary, however, not only with range but due to the nature of the target and the nature of the intervening terrain.

As a result of this experiment, a member of the Fire Control Section of NDRC informally prepared a section on training in range estimation which was included in the Instruction Manual for Gunnery for the Armored Force Schools.

The Princeton Branch of the Frankford Arsenal reports an experimental study of direct and differential range estimation without the use of instruments. (255) Direct estimation is made without the aid of known objects at known distances. Differential estimation was accomplished when known objects at known distances were available to aid in estimation. Observation for differential estimation was made through binoculars by 50 gunners and tank destroyer commanders. The test targets were half tracks at ranges from 400 to 2,765 yards. It was found that the probable error of a single range estimate by direct visual estimation ranges from 17 per cent to 32 per cent in different groups of men. A figure of 25 per cent is probably representative. On the other hand, the probable error of single range estimates by differential estimation, determined on the set of 30 half-track targets, was 14 per cent in each of the two groups of 25 gunners and tank destroyer commanders. It was found that the scatter was relatively small where the target was near a reference point and increased with increasing separation of target and reference point. It is natural to consider that errors in range estimation may be of three kinds: (1) a tendency of individual men to range consistently long or short on all targets; (2) a tendency for all men to estimate a particular target long or short; and (3) to other causes, not associated with (1) or (2) above. An analysis of the results indicates that the actual errors are a compound from all three sources.

To determine the relative accuracy of visual range estimation and of range finders, two field experiments were performed by the Bausch and Lomb Company at Fort Knox. The purpose of the first experiment was highly practical—to determine which of several existing instruments should be selected for immediate adoption as a range finder for tanks and also to determine which sort of instrument and which type of field should be further developed for an improved instrument for this purpose. (108) Six instruments were available:

- Keuffel & Esser—
  - Invert coincidence (1M, 12x)
- Keuffel & Esser—
  - Superimposed coincidence (1M, 12x)
- Keuffel & Esser—
  - Stereoscopic reticle (1M, 12x)
- Barr & Stroud—
  - Mark VI (1M, 14x)
- Perkins & Elmer—
  - Superimposed coincidence (48″, 6x)
- Polaroid—
  - Stereoscopic with bright line reticle (43″, 1x)

Ten targets were selected on rolling terrain at ranges from 646 to 5,939 yards and included such realistic targets as barns, telegraph poles, sign, tank semi-hull down, buildings on distant ridge, an isolated cedar tree and finally, a pylon for purposes of calibration of the instruments. The subjects consisted of ten men from an enlisted detail of Tank Corps personnel selected from an original group of 25 on the basis of standard vision tests. All subjects were untrained at the start of the experiment and at no time had knowledge of results or of true ranges. A total of approximately 15,000 readings were taken during a period of 3 weeks.

The raw data were reduced to a common basis so that it was possible to compute a "figure of merit" for each instrument. It was found that, in terms of per cent of error, the three coincidence instruments gave the best performance, with the Barr and Stroud Mark VI very much better than either of the other two coincidence instruments. However, in terms of UOE, the Polaroid instrument held an unchallenged first place, with the Mark VI a poor second. In this connection it will be remembered that the Polaroid instrument had the advantage of unit power. As a result of this experiment the Fire Control Section recommended the adoption of the Barr and Stroud instrument as an immediate solution of the problem. This recommendation concurred with the opinion of the Armored Forces and the instrument was designated as the M7.

Nevertheless, the results obtained with the Polaroid instrument were of great enough interest to warrant further study with this type of stereoscopic field, utilizing a bright illuminated reticle of the Wandermark type. Another reason of importance was the finding that one could press the illuminated reticle into a material background, such as trees, which was not possible with the normal opaque reticle of the usual stereoscopic instrument. Hence, the Bausch and Lomb Company fitted three stereoscopic Navy Mark 58 instruments for further tests at Fort Knox. The first of these was unmodified and contained the usual Navy opaque reticle. The others were modified so that the reticle of the second was an illuminated line and the reticle of the third was

an illuminated star. For comparison with the results of earlier tests, the Barr and Stroud Mark VI instruments was also included.

Four men of the original test group acted as observers and, at the end of the experiment, four men of the recorder group also took readings. Only two of the original targets could be seen because of foliage. In all, seven targets were used, at ranges from 1,190 yards to 2,793 yards. These consisted of the sign and pylon (from the earlier experiment), a hull down tank, a tank fully exposed head on, a truck with only a small part of the top showing through the trees, a truck partly obscured by shrubbery, and a bushy tree in the skyline.

The results indicate that, if equal weight is given to the various targets, there is a small, relatively consistent performance in favor of the Barr and Stroud invert coincidence field over the stereoscopic fields considered either from per cent error or UOE. However, if the results for a single target with very difficult background are eliminated, these differences in favor of the invert coincidence field tend to disappear. Evidence of considerable effect of target and background differences were importantly apparent. Little difference was seen among the three stereoscopic fields but the illuminated reticles were slightly better than the opaque reticle—the illuminated dot slightly better than the illuminated line.

These same four instruments were submitted to a factory test at the Bausch and Lomb Optical Company. (111) A Mark 57 B & L Coincidence instrument (1-meter base length) was added to the group. Three expert and three novice operators acted as observers. Six targets were employed at ranges from 1,013 to 8,137 yards, exhibiting differences in background and conformations both suitable and unsuitable for ranging with both types of instrument.

The results of this experiment indicate that the experts were better than the novices on all instruments. There is relatively little difference between these two classes of observer on the coincidence instrument. There were relatively great differences between the experts and the novices with the stereoscopic instruments. There was little difference in the results for all of the instruments when used by experts. The Mark 58 regular reticle range finder was poorest, for targets of this type, for both novices and experts. In a short subsequent experiment, to determine meteorological effects, the regular and illuminated star reticle instruments were ranged against a single target in very bad haze and rain. Under these adverse conditions, the star reticle gave considerably better accuracy of performance and slightly better precision.

Still another Bausch and Lomb report discusses the results of the several Fort Knox experiments. (110) This report also considers such general aspects, for the choice or development of such an instrument for Armored Force use, as ruggedness, stability and easy adjustability, convenience of use, portability, observer training, and the like.

Recommendations

As a result of these various experiments, the Fire Control Division of NDRC made certain recommendations to the Services. (39) (1) A fire control system involving the use of a range finder was recommended for units of the Armored Force and would be extremely useful for other arms of the Ground Forces. (2) The Barr and Stroud invert coincidence (1M, 14x) seemed to be the best immediately available instrument for use in the Armored Force situation. (3) In the further development of an instrument, consideration should be given to a stereoscopic instrument of the illuminated reticle type because such an instrument could be of extreme value for correction of range as well as obtaining initial range for opening fire. (4) With the increased accuracy of initial range to be expected with the use of a range finder, further investigation should be carried out to determine the most suitable fire control system. (5) With the stabilization of the gun in Armored Force units, consideration should be given to the development of a complete self-contained fire control system with linkage between the range finder and the gun.

Amplifying this last recommendation is a letter from the Chief of Section 7.4, NDRC, to the Office of the Chief of Ordnance. (579) The scheme contemplates the use of a range finder of stereoscopic type, the range knob of which is linked directly to the gun sight (or gun sight reticle) so as to introduce automatically the proper super-elevation. Two additional knobs (or perhaps preferably some form of joystick or course-and-speed indicator) are also provided. One knob would offset the gun sight by a fixed amount in azimuth; the other would offset it by a fixed amount in elevation, this latter amount

being in addition to the super-elevation introduced by the range finder. The contemplated procedure for this system would be for the tank commander, having selected his target, to introduce an azimuth deflection through the azimuth knob which, in his judgment, would provide the necessary lead to compensate for the cross component of the target's velocity. He would also introduce an elevation offset to compensate for the estimated range component of target velocity. The setting of these leads could conceivably be made by means of a course-and-speed indicator. Once made, these offsets remain fixed until intentionally changed. The tank commander would then range on the target, and the first shot would be fired. Through the range finder, which may now be thought of as a stereoscopic spotting glass, the commander would observe the error of the fall of shot. This error might be due in part to a false estimate of target's course or speed; it might be in part due to inaccurate boresighting, and in part due to such things as trunnion tilt, angle of site, and the like. Additional leads sufficient to correct it would be set into the sight by means of the azimuth and elevation knobs. The range finder would again be adjusted to present range, and the second round would be fired. This process would be repeated until a hit was secured.

The system has been described as if all the functions were performed by the tank commander. Various distributions of responsibility between gunner and commander are possible, and an important part of the design problem would be to select the best. The essential elements of the scheme are the correction of all those factors which can be expected to change but slowly with time through the medium of fixed azimuth and elevation deflections; and the correction of the one remaining factor, range, which can be expected to vary rapidly with time by means of direct coupling from the range finder knob.

A fire control system for the Gun Motor Carriage T 70 is proposed by the Princeton Branch of the Frankford Arsenal. (250) Tank targets, either moving or in full defilade at ranges up to 2,000 yards, are of the greatest tactical importance and the present fire control system does not provide sufficient accuracy to accomplish hits with the first or early rounds fired. Simple range estimation has proved to give errors of at least 25 per cent at least 40 per cent of the time. Actual tests of differential range estimation (i.e., in terms of known ranges to other objects in the field of fire, when these ranges have been previously determined by survey or with a range finder) give an improvement in accuracy over unaided range estimation which is discouragingly slight. Survey methods (determination of range by measuring angles at two or more separated points) are slow and subject to uncertainty in target identification and difficulty in the communication of data.

Hence the fire control scheme envisages the utilization of the invert coincidence range finder M9 for the determination of range and the Princeton Branch have devised a special mount for its use. On the vehicle, the instrument would be mounted on the 0.50-caliber antiaircraft gun ring. The mount and range finder may be quickly and easily removed for off-vehicle operation and, in this case, a unipod is provided as a support. Binoculars M3 are collimated with the range finder and brow pad, eyeguard, and soft rubber eyepieces are provided. In both on- and off-vehicle operation the commander determines the range and announces to the gunner. Other aspects of the fire control system need not be developed here.

The theoretical expected performance of a hit on first round with the proposed system on a stationary target as compared with the present method at 2,000 yards is: for head on tank (2 x 2 yard target) 0.16 as against 0.4 with range estimation and 0.06 with range card; for broadside-on (2 x 6 yard target) 0.32 for proposed system as against 0.09 for visual estimation of range and 0.16 for use of range card. The comparison of the probability of hitting on the first round and of hitting a tank in hull defilade (½ x 2 yard target) at 2,000 yards is 0.045 by proposed system as against 0.015 with visual estimation of range and 0.03 with use of range card. Data are also given for estimated performance against moving tank targets and, at 2,000 yards, show ratios of improvement of the proposed system to the present system in ratios of approximately 3 to 1.

Australian Range Finding Sight

For Armored Force application, a range finder sight system with linkage to the gun was developed by a group in Australia. This is fully described in a British report which also records non-firing trials with the system by the British Tank Armament Research Committee. (546) The instrument was designed to transfer rapidly and automatically the range measured by the range finder to the moving reticle of the sighting telescope in terms of tangent

elevation. An 80-cm base range finder (Infantry No. 12 Mark IV) is coupled to a X3 episcopic telescope, provided with a moving reticle. The range finder and telescope employ a common eyepiece, a moving prism allowing the optical path to be transferred from one instrument to the other. Both the rotation of the prism and the coincidence setting of the range finder are controlled through flexible drives and a milled knob situated conveniently for the gunner. The operation of setting the range finder into coincidence moves the horizontal crosswire of the sighting telescope into such a position that laying it on the target will automatically impart the correct range table tangent elevation for the range in question and the gun and ammunition. Throughout the present tests, the actual range in yards was unknown to the operators.

Results show that the mean deviations obtained with the Australian range finding sight were about one and one-half times as great as with Infantry Range Finder No. 12 and that the Australian sight failed in fading light slightly before the Infantry instrument. The accuracy of the transfer of range from the range finder to the telescope was adequate. The Australian range finding sight showed a net saving of about 10 seconds over the conventional range finder and fixed reticle sighting telescope in finding the target, measuring its range, and laying the gun. It is noteworthy that the mean deviations in range determination increased, with both range finders, by a factor of 3.5 times, when the operators knew they were being timed. It was also noted that the halving of the range finder sight lost its adjustment during cross-country runs of about 3 miles.

Firing trials with the Australian system are given in another T.A.R. report. (547) These report a comparison of the Australian system experimentally mounted on a Centaur Tank and the ordinary No. 39 Mark 1 telescope with fixed reticle in a Cromwell III tank. Both vehicles mounted a 6 pr 7 cwt H.V. gun and H.E. Mark I.T. ammunition was used against targets representing hull-down tanks at ranges between 800 and 1,500 yards. Trials were carried out in hazy winter daylight. Four experienced tank commanders and four gunners familiar with the ordinary and the Australian methods were used in the trials. The results show that the Australian range finding sight offers a saving of at least 3½ rounds in number of rounds and at least 2½ minutes in time spent in bringing the target within the 90 per cent range zone of the gun, when compared with the normal method of visual estimation of range and use of a fixed reticle. On four target pairs the number of rounds necessary for a hit were, for the Australian range finder sight: 6, 4, 1, and 7 as against the normal method of 16, 8, and no hit after 10 and 12 rounds. However, T.A.R. point out that the Australian system would be difficult to fit into existing tanks and would require extra holes in the front or side armour and that it could not be used for turret-down fire. Certain modifications of the system are suggested, such as the introduction of a range scale so that the information could be passed to other tanks and adjustment for different types of ammunition and different muzzle velocities.

15.1.3 Range Finder Fields

The results outlined above indicate that there may be a considerable effect of the type of field used when ranging is against indistinct targets of the ground type, characteristic of Armored Force or Ground Force combat. Hence the Princeton Branch of the Frankford Arsenal attacked this problem of range finder field experimentally. The first report deals with the precision and consistency for three observers using eight fields on three targets for a total of about 5,400 readings. (241) The fields compared were:

1. Superimposed coincidence
2. Erect coincidence
3. Invert coincidence, ortho motion
4. Invert coincidence, pseudo motion
5. Invert ortho-pseudo
6. Erect ortho-psuedo
7. Ortho stereo, with reticles
8. Pseudo stereo, with reticles

The experiments were performed on the Eastman Trainer, using vectograph photographs of ground targets. The results again indicate that there are differences in relative performance of the various fields with different targets. Hence an analysis was also made using the tank targets.

The results of this analysis indicate that the superimposed coincidence field appears definitely inferior in precision and consistency. Erect ortho-pseudo appears inferior in precision, though its consistency performance is good. Pseudo-stereo is inferior in consistency. The invert coincidence ortho has the best relative position of the eight fields for both consist-

ency and precision. No results for accuracy were obtainable by this method. A description of the various fields is included.

In another experiment, performed by the Princeton Branch of the Frankford Arsenal, a comparison of fields was made with the Mark 4 Trainer again employing the same three vectographic targets. (242) This comparison was primarily between invert-foreground and invert-sky combinations. The targets were presented in monocular, split-field invert coincidence and binocularly in ortho-psuedo stereo, using the foreground- and sky-invert in both cases. The results indicate that averaged over all four observers, no significant differences were found between coincidence and ortho-pseudo presentation or between invert sky and invert foreground for this sort of ground target. However, individual observers showed marked differences in performance with respect to type of presentation.

The Princeton Branch of the Frankford Arsenal reported an analysis of fire control design for A.P.C. projectiles. (246) This is a theoretical study of various factors which may affect this problem. It presents, in both tabular and graphical form, the required accuracy of ranging to obtain a given accuracy of trajectory location and the expected accuracy of various range finding devices. The graphs and tables of this memorandum are intended to serve as a basis for estimating the probable efficiency of range finding devices and for comparing different instruments of this sort. Methods are given for translation into comparable unit instruments which may vary in base length, magnification, and corrections as a result of different weather conditions. Data regarding ranges for different degrees of elevation for the M61 and M62 are given. The study concludes with the statement that visual estimation of range is only satisfactory at ranges well below 1,000 yards when using these projectiles.

The Princeton Branch has performed some experiments and has entered into a theoretical discussion to study the problem of sensing shots from the 76-mm M1 gun mounted on motor carriage T 70. (249) They conclude that present sensing accuracy in regard to fall of shot is insufficient to take full advantage of the inherent accuracy of the gun. One suggestion for the improvement of this sensing accuracy might be the use of a range finder as a sensing instrument. The M9 Range Finder was tested, but as it stands, is not well adapted for use as a sensing instrument. The investigators believe it is possible that a range finder such as the T16E1, in which the upper half of the field is duplicated, might be of some value in this regard.

15.2 SOME STUDIES OF SIMULTANEOUS TRACKING AND STADIOMETRIC RANGING

15.2.1 Simultaneous Hand and Foot Operation

At the request of the Naval Bureau of Ordnance, the Foxboro Company did several experiments on simultaneous tracking and stadia ranging for small caliber antiaircraft guns. (221) The first was a field study involving the ranging and tracking of 431 actual crossing flights, of which 71 were rejected because of photographic recording difficulties. The study involved the measurement of over 15,000 frames of moving picture film. Three types of stadiometric reticle were used: an illuminated ring, an illuminated disc and six illuminated pointed dots. Tracking was done by the usual handle bar assembly and ranging was accomplished by pressure on a foot pedal with both feet. The results show that there are no signficant differences between these three types of reticle so far as ranging accuracy is concerned, but that the ring is definitely inferior to the dots and disc in tracking accuracy. These conclusions hold for a wide variety of sun and sky conditions during the tests but with twilight and dark conditions excluded.

It was found that the task of ranging and tracking simultaneously is difficult for the inexperienced Naval operators used in this test, who tend to concentrate now on one and again on the other aspect of the operation. Both variability from test to test and the ratio of poorest to best operators are greater in ranging than in tracking, indicating that ranging is more difficult. No evidence of improvement was found during the tests due to the limited amount of practice afforded. But it is very probable that operators would show definite improvement in these two simultaneous operations, especially in ranging, with training and considerably more practice.

In these field tests, the majority of operators tended to range short, that is, to make the diameter of the reticle larger than the largest dimension of the target. Less than 10 per cent of all measured frames showed the opposite tendency. The largest

ranging errors were found with larger reticles or shorter ranges both because of the increasing rate of change in target velocity and because of greater difficulty in matching the larger extents visually.

Although the tests were made primarily to obtain stadia ranging data, information regarding types of tracking errors was obtained from viewing films of the tests as well as from measurements of the frames. Rough quantitative checks of moving pictures of the tests revealed tendencies toward different constant elevation errors with the three reticle patterns. With ring, the tendency is to center the target in the upper half of the circle while with the disc, the tendency is to center in the lower half. With the six dot pattern, which was the only one having a center dot, there was a tendency to center the target in the upper half but the elevation errors were much smaller, and the total time off target was much less than with the other two patterns. Since total tracking error as shown by measurements of the individual frames was equal for dots and disc, it would appear that the center dot is of value in reducing elevation error rather than azimuth error.

For regular flights the per cent ranging error for the average of all operators was 45 for ring, 47 for dots, and 39 for disc while the tracking errors in mils were 15.6 for ring, 7.6 for dots, and 7.4 for disc. In certain special courses of accuracy of ranging in flights across the sun, the ranging errors in per cent were increased to 66 for ring, 83 for dots and 60 for disc while the tracking errors in mils was increased to 26.0 for ring, 15.3 for dots and 13.6 for disc. The method of obtaining the dot pattern is described and illustrated in the text.

These results and the magnitude of the errors obtained were not encouraging from the point of view of accuracy of fire. However, it will be remembered that the operators used in the first field experiment were not trained or experienced in these simultaneous operations. Hence the Foxboro Company subsequently did a laboratory experiment to estimate the feasibility of training a man to operate simultaneously triple controls for following a target in azimuth, elevation, and range. (221) A hand and foot technique was used in which azimuth and elevation were tracked by varying combinations of side-to-side and up-and-down movements of wide handle bars while an activity like ranging was achieved by pressing with the feet on either side of a pivoted cross-bar. In an additional experiment, a pair of opposed-action pedals were substituted for the crossbar. Throughout the experiments the tracking and stadiometric ranging were accomplished while viewing a circular target through a reticle having a center dot and hexagon pattern of variable diameter.

The results with both the crossbar and opposed pedal forms of foot control demonstrate that under favorable conditions in 2 or 3 hours considerable proficiency is possible in simultaneous hand and foot functioning. All operators were successful in developing this coordination. The simultaneous functioning, however, reduces the accuracy of separate manual and pedal functioning. Even under favorable conditions, 10 hours of practice (100 runs) may be required to compensate the added difficulty of the triple performance. More accurate simultaneous functioning followed 4 hours preliminary practice on a single function than 4 hours in the simultaneous function. Under such circumstances, 5 or 6 hours of simultaneous functions were sufficient to compensate for the added difficulty. During the simultaneous performance, greater improvement was in the ranging when the initial training was only in ranging; it was in the tracking when the initial training was only in tracking. A significantly greater advantage was secured in the case of tracking, presumably because of the significantly greater difficulty of the tracking operation.

The ranging scores with the crossbar and with the opposed-pedal foot control did not differ significantly in accuracy. The pedals, however, may be rated slightly higher on three counts—less foot slippage, slightly better score and unanimous operator preference. It is pointed out that the foot-hand controls of the sort investigated are open to criticism because the coordinations might break down under strain or distraction and because the feet are often needed to support or brace the body during manipulations of hand controls.

15.2.2 All-Hand Operation

The Foxboro Company reported another study on simultaneous tracking and stadiometric ranging. (226) This is a comparative study of all-hand controls, by handle bar tracking in azimuth and elevation plus twisting motorcycle grips for ranging versus handle bar tracking with the hands plus double pedal ranging with the feet. The results of 21 subjects

indicate that operators may learn either type of control for the simultaneous triple operation. The results indicate the same order of accuracy in the all-hand performance as in the hand-foot performance. This result was true for highly practiced operators as well as for a new group having no previous training in either tracking or ranging. The hand ranging, while hand tracking, did show slightly higher accuracy than the foot ranging, while hand tracking, but the difference did not prove to be significant. Learning curves are given and the new operators demonstrated marked practice improvement during 5 hours of simultaneous tracking and ranging with either type of control. Also, changing the sensitivity of the hand ranging control, by a factor of two, gave rise to no significant change in accuracy either of the ranging itself or the simultaneous tracking.

15.2.3 Single Versus Double Pedal

A final Foxboro Company report in this series contrasts results with three types of foot ranging controls while simultaneously tracking in azimuth and elevation with handle bar controls. (227) The three types of foot control used were opposed double pedal and two accelerator type of right foot pedal actuated by pressure against a spring, in one case hinged at the instep and in the other case hinged at the heel. Springs of three degrees of stiffness were used in each of the accelerator types of foot control, giving mean operating pressures in pounds from 1.5 to 11.5 for the central hinged pedal and 3.5 to 18.3 for the heel hinged control. In all three cases, pressure of the right foot increased the diameter of the stadia ranging reticle, which was of the dot pattern. Eight trained and six untrained observers acted as subjects, the latter being put through 7 hours of practice with each type of control.

The results show that no significant difference in accuracy was revealed for simultaneous direct handle bar tracking and foot pedal ranging regardless of whether the foot pedal ranging was accomplished with two feet on double opposed pedals, with one foot on a single spring pedal hinged under the instep, or with one foot on a single acceleration-type of pedal pivoted at the rear of the heel. For the trained observers, who had previously been practiced in double pedal operation in a former experiment, showed a greater accuracy of 5-10 per cent for this type of control. No significant effects on pedal operation resulted from the sensibly obvious changes in spring resistance employed. Finally, no consistent operator preferences were reported either with respect to pedal type or to spring tension. For every operator and for every type of ranging control, there was greater ranging error while simultaneously tracking than when ranging alone.

15.2.4 Conclusion

These several studies on simultaneous tracking and simultaneous ranging have been gathered into a single report attached to a Report to the Services issued by the NDRC Fire Control Division. (42) The following recommendations are made.

1. Inasmuch as no significant differences were discovered for several types of ranging controls while doing simultaneous handle bar direct tracking in azimuth and elevation, it is safe for designers of such instruments to introduce motorcycle grip, opposed two foot pedal or spring opposed single pedal controls into new designs depending upon the position of the operator and/or the space restrictions present. It may be noted, in the case of a highly unstable platform, that the single foot control may be preferable to the use of both feet because, in this case, the operator could then firmly plant his unused foot for greater support and stability.
2. The disc pattern reticle for sights of the type of the Mark VII should be given further field test with trained Service personnel.
3. Operators should receive very considerable training in simultaneous azimuth and elevation tracking and stadiometric ranging before they are called upon to use this difficult operation in combat. The preliminary training should start with 3 to 4 hours tracking alone before stadia ranging is added to obtain the best results in the shortest time.

Chapter 16

RETICLE DESIGN

16.1 INTRODUCTION

The problem of reticle design was in the minds of a number of NDRC investigators early in their contracts. One early study was made at Tufts College in an effort to produce a simpler reticle pattern which might even give better accuracies and precisions than the standard types. (562) Another important aspect was that the proposed design would be less affected by target position. The reticle consisted merely of the outline of a circle subtending 34 minutes of arc as the fiducial mark. This circle should determine a fiducial plane against which the target should be ranged. The results showed that such a reticle helps, in some cases, to overcome the target position effect when the operator is instructed to range by keeping the target in the center of the circle. Ranging on a stationary target, the accuracy of two of the six subjects, with the target placed in the middle of the circle, was significantly better than it was with the under-circle or above-circle positions. One observer had a larger constant error in the middle-of-circle trials than he had in either of the above or below trials.

Some early experiments on reticle design were conducted at Brown University. For this purpose they developed a special apparatus (126) for the comparison of stereoscopic settings with different reticles. The apparatus, which is fully described in the text, allows for rapid change of the reticle patterns which are presented to the subject and for a maximum of reproducibility in reticle position relative to the target. Illustrative results are given for five reticle patterns: Navy Post and Navy Diamond, standard Army, a reticle in which the fiducial mark consists of two concentric circles in a larger cross-hatched field all in the same plane (Riggs reticle), and a photographic reticle showing two chimneys above a building as the fiducial marks. No data are given with this last reticle pattern. These are also described in a second report. (119)

The preliminary data for three subjects show the following rank order: Navy Post, Navy Diamond, Army, and Riggs reticles. The differences, however, are not very great. The report emphasized in the analysis that day to day variations in subjects are ordinarily large enough to swamp differences in the settings which may be obtained with different reticles under proper conditions. This low consistency of these results was probably due to changes of criteria of contact and it is emphasized that further work on reticle design should probably initially emphasize aids in maintenance of uniform criteria of judgment of stereo contact.

16.1.1 The Full-Line Reticle

Several reports from the Princeton Branch of the Frankford Arsenal are concerned with experiments dealing with a new suggested form of reticle pattern. These are called full-line reticles and consist of one or more vertical lines extending across the entire field. (260) It is hoped that these full-line reticles may reduce the bad effects of errors in height adjustment between fiducial mark and target. Such reticles with one and two lines were tested against standard reticle in the M6 Stereoscopic Trainer. This instrument provides (1) targets of fixed range, (2) targets moving in range without tracking errors, (3) targets moving in range with tracking errors in azimuth or elevation, and (4) targets moving in range with tracking errors in both azimuth and elevation. The single line reticle consisted of a single line running vertically and centrally across the whole of the apparent field. This line had an apparent width of approximately 0.5 mils or 8 UOE. The double line reticle consisted of two similar lines parallel with a separation of 30 mils—the combination being centered in the field. Simulated airplane targets in different shapes, sizes and attitudes were used. Different positions of reticle and target were employed. Observations were made by two practical subjects. The results indicate that, under these conditions, the performance of the full-line reticles was not inferior to the standard reticles and it is recommended that further consideration be given full-line reticles as a means of reducing the ill effects of height-adjustment error.

A second report from the Princeton Branch of the Frankford Arsenal gives further results of work with reticles of the full-line type. (261) The single line reticle and a double full-line reticle with a separation

of 125 mils and the standard reticle were used in the M6 Steroscopic Trainer. Two sets of vectograph targets were used – one selected for good and the other for bad height adjustment. The same two observers were used. Only the variability of the median settings is reported. The results indicate that no clear or consistent superiority of any of the three reticle types was apparent for any one target. However, it appears that there were statistically significant differences between the relative performance of the different reticles on the targets in height adjustment as compared with those out of height adjustment. Using the geometric mean as a measure of average performance, the standard and single line give larger errors when the target is out of height adjustment while the double line gives slightly better results under these conditions. The investigators point out that, while the differences between these values are statistically significant, it is not clear that much practical importance is to be attached to them. The level of variability obtained was very largely dependent on the particular targets and vectographs and it seems unsafe to generalize too far. It would seem especially dangerous to apply the results to range finder practice without considerable additional evidence. However, it is interesting to note, subject to the limitations above, that on the whole the standard reticle performs consistently well in both in and out of height adjustment series.

The problem of reticle design seemed of sufficient importance so that a systematic program on this topic was initiated at Brown University. This program was not particularly designed to pick out the best reticle of the existing patterns or of any other paterns which might be devised, but rather sought to determine the good and bad principles for the design of reticle patterns.

16.1.2 Imperfections in the Reticle Field

A preliminary series of Brown University studies investigated the question of the effect of imperfections in the reticle field of stereoscopic range finders. This was an extremely practical problem because in 1943 and earlier it was reported that manufacturers were experiencing difficulty in producing a sufficient supply of perfect reticles. It was subsequently understood that this difficulty was overcome completely, though at the cost of substantial numbers of rejects. However, at that time, it seemed advisable to study the problem of reticle inspection as well as the possible effects of small spots or imperfections on the reticle field. The first Brown study had to do with the reliability of reticle inspection. (161) A series of 30 reticle blanks, showing various degrees of blemish, were examined by five members of the regular inspection staff of a manufacturer. The same group was retested with the same blanks 2 months after the initial examination. The results demonstrate great differences in judgments among inspectors in both test and retest. Thus, although an inspector may be reasonably, although not extraordinarily consistent with herself, she may nevertheless be completely out of line with other inspectors. For example one inspector rejected 30 per cent of the blanks on the first test and 20 per cent of the same blanks on retest; while another observer rejected 86.7 per cent and 73.3 per cent of the same blanks on test-retest respectively.

The second report from Brown University deals with an experimental study of the effects of imperfections intentionally introduced into the reticle field. (162) These consisted of opaque circles of different sizes and, in every case, these intentional imperfections were of considerably greater magnitude than any which would ever be encountered in a field instrument. In this experiment only settings on fixed targets were employed. The results indicate that the presence of such imperfections result in a very slight and statistically unreliable decrease in precision of stereoscopic setting and a probable decrease in the consistency of such settings. There is some slight evidence, again statistically unreliable, that the extraneous stimuli in the reticle field influence settings in the direction of giving "short" readings. However, the general conclusion of this report is that the presence of imperfections of the magnitude introduced has no great effect on stereoscopic settings.

In order to determine if these findings would be confirmed if both stereoscopic movement and tracking errors were introduced into the ranging situation, Brown University did an additional dynamic study which is described in a third report. (174) Under these more exacting conditions of observation, when imperfections, for which fusion was both possible and impossible, were introduced and with stereoscopic movement and tracking errors also present, it was found that the presence of the extraneous forms in the reticle field produces no appreciable

effect on the precision or accuracy of ranging.

These three Brown University studies form the supporting data of a Report to the Services issued by the Fire Control Division of NDRC. (40) This report makes the following recommendations: (1) That greater uniformity of inspection and resulting saving of materials would probably be effected by manufacturers' introduction of objective quality control systems, such as use of specimens with known degrees of imperfection for comparison by inspectors of both reticle blanks and of finished reticles. (2) The using Services should inform stereoscopic range finder observers, both in training and in the field, that slight imperfections which may appear in the reticle field should be ignored because they will not affect the quality of range finder performance.

Another special study was made by Brown University on a comparative study of the design of internal adjuster targets for range and height finders. These studies (139, 142, 143, 158, 159) are attached to a Division 7 NDRC Report to the Services. (31) These reports are described in the section on Calibration of the Instrument in this present summary and are mentioned in this place solely for the sake of completeness because they deal with the design and pattern of a reticle target but on a type of problem quite different from the one presently under discussion.

16.2 EXPERIMENTS ON RETICLE PATTERNS

We now turn to the description of the several experiments reported by Brown University in their systematic study of the design of reticles for stereoscopic range and height finders and of the determination of the systematic principles underlying the various kinds of patterns which might be designed. The first set of experiments dealt solely with opaque reticle patterns. The apparatus employed in many of these experiments is adequately described and illustrated. (170) The instrument was especially developed for the purpose of comparing designs proposed for use in the reticle field of a stereoscopic range finder. The instrument makes possible the rapid exchange of one reticle design for another so that several designs may be used successively during the course of a single experimental period. The reticles and targets are provided by large photographic plates. The size of the plate is such that the common photographic flaws of specks, scratches, pinholes, and the like are not discernible by the observer. The left and right reticle plates for each design are permanently cemented side by side to a common backing of plate glass, thus assuring a constant disparity between corresponding points in the field. The targets are provided with narrow, vertical slits which may be superimposed upon the central lines of the reticles for purposes of establishing a true zero error of ranging. No optical system of projection or collimation is involved, since reticles and targets are in essentially the same physical plane. Small variations of azimuth and elevation of the target can be introduced in random fashion by a mechanical system which simulates typical tracking errors. Random variations in depth can also be introduced and the task of the observer is to maintain stereoscopic contact between the target and the reticle by the use of a range knob.

16.2.1 Approximating Zero Error

The method for approximating the point of zero error or true range in ranging on artificial stereoscopic targets within a reticle field had been previously described in a Brown University report. (138) The essential feature of the method is the provision that the distance between target images for the left and right eyes shall be the same as the distance between the central fiducial lines of the left and right reticles. This is accomplished by observing the right field monocularly and establishing an optical coincidence between a fixed point on the reticle and a corresponding point on the movable right image of the target. These corresponding points are so placed that, when they are in coincidence, the target images are automatically of the same disparity as the center post images for the two eyes. The coincidence can be established with a high degree of precision and with small variation from observer to observer. Hence the method is useful for measuring accuracy of performance in a stereoscopic research instrument as well as precision and consistency which could be obtained without its use. Experiments with six subjects indicate that the monocular coincidence observations have a greater stability, with respect to both precision and agreement among observers, than do stereoscopic observations made under similar conditions. The mean of the individual values for average deviation is 0.74 UOE for stereoscopic observation and only 0.36 UOE for monocular.

16.2.2 Types of Course Used

Another report of the Brown University group discusses certain methodological considerations having to do with the type of course used in experiments on reticle design and the reliability of the observers' determinations. (172) These experiments are concerned with an analysis of two factors which are represented in the reticle pattern experiments but not in military range finding: (1) the effects due to the use of a random course and, (2) effects due to the manner in which the observers' records are obtained. The first series of experiments, here reported, demonstrated that the basic "random movement" ranging course employed does not give results greatly different from those given by a course comparable to those encountered under field conditions in antiaircraft work. The course respresenting field conditions is essentially a "sine wave" course which gives an apparent change in range, first through an increase and then through a decrease for a crossing course. Further experiments are concerned with six conditions of target presentation. These were: (1) random and erratic stereoscopic movement with simulated tracking errors; (2) no stereoscopic movement but simulated tracking errors in which the observer throws the target off after making contact and makes a new setting; (3) random stereoscopic movement but no tracking errors; (4) sine wave stereoscopic movement with tracking errors; (5) stationary target with target nose placed directly under 5 minutes below center post of reticle and no tracking errors; (6) stationary target with nose 5 minutes below and 47 minutes to right of the center post of the reticle and no tracking errors. The Navy line reticle was used and 10 experienced observers each made 50 range readings for each condition. The results indicate that the introduction of stereoscopic movement caused a statistically reliable decrease in the precisions of making range settings. The effects of tracking errors on precision are not great by comparison with effects of stereoscopic movement. The mean precision scores for each condition in UOE were: (1) –3.58; (2) –3.28; (3) –3.44; (4) –3.44; (5) –3.13 and (6) –2.95 UOE.

16.2.3 Factors Affecting Precision

In still another experiment the Brown University group ascertained the reliability of readings made by different observers when the random movement course was used. Small differences in readings were shown among the three experienced observers employed. However, the differences were well within the limits of accuracy which may be expected in the field situation when due consideration is given, e.g., to the range transmitter problem. An experimental design which will absorb variances due to observer differences in readings is suggested in the report. The average discrepancies for constant error or accuracy were 0.50 UOE and for precison were 0.33 UOE.

A preliminary experiment at Brown University compared the precisions of settings made with four present standard Service reticle patterns. (160) These were the Navy Solid Diamond, the Navy Open Diamond; the Navy Line and the Army. Observations were made with timed intermittent readings on a stationary target by eight practiced observers divided into four groups of two observers each. The experiment was so designed that each group of observers viewed the reticles in a different sequence, a procedure aimed to balance out effects due to practice and fatigue. The mean values for precision, expressed as average deviations from individual mean settings in seconds of arc are: Navy Line: 19.2; Army: 19.5; Navy Solid Diamond: 22.2; and Navy Open Diamond: 23.8. The factor of reticle design makes a contribution—significant at the 5 per cent level—to the variance of all the average deviation values. The slight superiority of the Navy Line reticle evidenced in these experiments is in line with a similar finding of a previous experiment when bracketing ad lib was allowed. The present experiments do not provide any data on what might happen under conditions of continuous contact.

Fore and Aft Marks

The Brown University group attacked the problem of fore and aft marks and of their position. The results are given in two reports. (163, 165) The first of these experiments is concerned with a preliminary comparison of the effect of apparent position of fore and aft reticle marks on the precision of stereoscopic settings. Results were obtained on 11 reticle patterns, with fore and aft marks at various combinations of 7.5, 15, 30, 60, and 120 UOE from the control line of Navy Line reticle. A reticle with no fore and aft marks was used for comparison. The experiment was so designed that the five experienced observers viewed the reticles in different sequences. Readings

were made at 10-second intervals on a fixed simulated aerial target. The fore and aft marks were presented singly at the different apparent distances and in consecutive pairs at the different apparent distances from the fiducial line. It was found that the smallest average deviations are yielded by reticles in which single pairs of fore and aft marks are located at 30 to 120 UOE from the central line. The poorest precision was given by a reticle with single pairs of fore and aft marks at 7.5 UOE. Reticles with other combinations of fore and aft marks lie between the extremes. A reticle with no fore and aft lines gives next to the poorest precision. The precisions of the different combinations in rank order in seconds of arc are: 30 UOE: 14.9 seconds of arc; 120: 15.2; 60: 15.4; 120, 60, 30, 15 and 7.5. All present: 16.7; 60 and 30: 17.3; 15: 19.0; 15 and 7.5: 19.1; 30 and 15: 19.4; 120 and 60: 19.4; no fore and aft marks: 21.4 and 7.5: 22.3.

These results indicate that highest precision is obtained with reticles having single pairs of fore and aft marks 30 UOE or more from the central lines. In order to determine whether the single-pair fore and aft marks are reliably better than other combinations, the investigators performed an analysis of variance in which the three single-pair reticles which had the highest rank orders were contrasted with all others. The results of this statistical treatment show that observer to observer variance is significant at the 1 per cent level and that variance within the two classes of reticles is significant below the 1 per cent level. Hence the investigators conclude, as a general principle, that single pairs of fore and aft marks disposed at sufficiently great distances from the central line, provide advantageous conditions for making stereoscopic settings. Fore and aft marks placed too near the central line or too many fore and aft marks in any reticle pattern seem to be disadvantageous, at least for ranging on fixed targets.

The second Brown University experiment dealing with the positioning of fore and aft marks in the reticle field is described in a second report. (165) In the previous experiment, these marks were so varied in separation as to provide the impression of perspective lines crossing at the central post. In the present study, the investigators are concerned with precisions with fore and aft reticle marks which vary in apparent distance from the central line but which maintain the same lateral separation throughout the range in depth. Single pairs of fore and single pairs of aft marks were disposed at the following stereoscopic UOE distances from the central line: 7.5, 15, 30, 60 and 120. The lateral distance between reticle lines in each pair was constant at a separation covering 13 per cent of the distance between the two posts adjacent to the central post in the central line of the Navy Line reticle. As seen in depth, the fore and aft marks seemed to be disposed symmetrically—in the lateral plane—about the central post of the reticle.

The results show that precisions for fore and aft marks lying at 7.5, 15, and 30 UOE from the center are, as an average for five subjects, about 16.5 seconds of arc. The precision decreases for the lines at 60 and 120 UOE to between 25 and 30 seconds of arc. The decrease in precision shown for the two later reticles was accompanied by the qualitative finding that fusion of the reticles was impossible for all subjects under these conditions. Hence, from the point of view of reticle design, it would seem that fore and aft fiducial marks at great distances from the center line should be disposed with wide separations in the sterescopic plane.

Differences in Configurations

A more elaborate experiment was planned by the group at Brown University to answer a number of questions: (1) Do changes in "psychological configuration" of reticle pattern cause changes in precision of stereoscopic setting? (2) Does length of fiducial line influence precision of setting? (3) Does precision of setting with a horizontal fiducial mark differ from precision of setting with a vertical fiducial mark? (4) What is the influence of "peripheral mass" on precision? (5) What is the influence of lateral separation of full-line fiducial marks on precision? (6) What degree of precision is obtained with two "miscellaneous reticle configurations"? (168)

The same apparatus and 11 experienced observers were used at different times and on different groups ranging with a total of 17 reticle patterns. Stereoscopic settings on fixed targets simulating aircraft were made at timed 10-second intervals. The experiment was divided into three series. The philosophy underlying the first series started with the hypothesis that the function of a reticle is to define a plane in space. From this point of view, it is important to know whether certain types of configurations, by their "psychological relationships", define planes more adequately than certain other kinds of configurations. Complete analysis of this problem would require determinations on an infinite number of

configurations and hence is not practicable. Nevertheless, it is of some value to determine whether differences in configurations lead to differences in precisions of ranging. For example, does a particular reticle show greater internal cohesiveness in defining a plane than another type of configuration? Reproductions of the reticles used in this and the other series are given in the text. Five reticle designs were used in the first series: (1) A reticle in which there is an insistence of long vertical lines with breaks in the center. (2) A symmetrical radiating pattern, filling most of the visual field, in which the fiducial marks are short vertical lines, 21 in number. (3) A variety of fiducial marks consisting of a short central vertical line surrounded by four different letters of the same height. (4) A pattern in which opportunity is given to enclose the target by a geometric figure inasmuch as the central line is enclosed by a rectangle with two other vertical lines placed laterally outside this area. (5) This is similar in principle to reticle (4) and is a modificaton of the circle reticle to fulfill the conditions of target position. In this reticle, segments of a circle are joined by vertical lines enclosing a short central line. In all of these patterns the length of the central line is the same and the nearest surrounding lines are at the same distance. Also, the target was always placed in the same relative position laterally and below the central line.

An analysis of variance of the results on the precision values shows that variance due to observers is significant at the 1 per cent level and variance due to reticles is not significant at the 5 per cent level. Except for the fifth reticle, which gave exceptionally poor precisions, the reticles of this series do not result in great differences in precision of performance. These results would indicate that emphasis on such principles as numerous radiating fiducial marks filling a large part of the field; dissimilarity of fiducial marks; the provision of geometrical figures within which the target appears; and the provision of long lines do not, under the present conditions, give results which indicate tremendous superiority of one pattern over another. Hence, rather than emphasizing further work on configurational factors, it would seem that a more fruitful approach would be along the line of examining reticles which provide enough comparison fiducial marks in such aspects that the operator is given a maximum opportunity to make precise settings, when due consideration is given to tracking errors.

The second series of reticles contain four patterns designed to test the influence of length of line in precision of setting. These have the following forms: (1) Full single line to left so that target may be centered in the field close to the line; (2) Short vertical single in same position; (3) Single full vertical single line with break just below center of field; (4) Short vertical single line with break in similar position. Two other reticles were constructed to allow for an evaluation of precisions obtainable with vertical as contrasted with horizontal lines, the target appearing in comparable spaces between the lines. For this purpose two reticle patterns were developed; (5) A single vertical line through the center of the field with a larger break than (3) above, and (6) two parallel horizontal lines separated by the same amount as the break in (5).

The results indicate, by an analysis of variance for the class long-line reticles versus the class short-line reticles that variance due to subjects is significant at the 5 per cent level and variance due to class is significant also at the 5 per cent level. These are results with fixed targets and it may well be that the longer length of line may be valuable in giving opportunity to the observer to make precise settings with changes in the position of the target if tracking errors are present. In the second comparison in this series of experiments, the results show that vertical lines give better precisions than horizontal lines—comparison of reticles (5) and (6)—and that this difference is valid and reliable at the 1 per cent level. This difference was markedly present for four of the five observers used in this part of the experiment.

In a third series of experiments, the results of which are given in this same Brown University report, six more reticles were developed to answer certain specific questions. They are considered in pairs. Reticles (1) and (2) present full-line configurations, the target appearing in comparable positions between the lines. Reticle (1) is a full line reticle with six evenly spaced vertical lines across the entire field. Reticle (2) has exactly similar lines but there have been added two large dark masses at the top and bottom of the field. It has been suggested that the presence of such masses might better define the plane to be used for ranging against the target as well as leading to better fusion of this plane in space. The results indicate, however, that reticle (2) does not give better precision than reticle (1) and hence the result does not justify the conclusion that a "pe-

ripheral mass" enhances precision of setting except in the cases of two of the ten observers used.

Reticles (3) and (4) were constructed to test the influence on precision of a series of broken vertical lines, disposed throughout the stereoscopic field. Reticle (3) consisted of 7 broken vertical lines evenly spaced. Reticle (4) had 21 similar broken lines evenly spaced but obviously closer together than the separation between lines in reticle (3). The results show that reticle (3) with the wider separation of lines was reliably better than subject precision with reticle (4) at the 5 per cent level. This was true for eight of the ten observers. Subject observations indicate that reticle (4) is a poor configuration. Fluctuations in localization of this reticle occurred very frequently due to "horizontal slip" or the fusing of unpaired lines. All subjects agree in this observation. Thus it seems that parallel vertical lines in a reticle pattern should be displaced from one another through such a distance that equivocal fusion is avoided. More will be said about horizontal slip later in this section.

Reticles (5) and (6) present two miscellaneous designs. Reticle (5) is the closest approximation to the design of the German R40 instrument described by the Frankford Arsenal. (228) It consists of three small solid diamonds with two smaller rectangles between evenly spaced in a horizontal line. Reticle (6) consisted solely of a circle placed in the middle of the field. The results for reticles (3), (4), (5), and (6), as tested by analysis of variance indicate that variance due to observers is not significant at the 5 per cent level but that variance due to reticles is significant at the 1 per cent level. The rank order of precisions is (6) (the circle reticle); (3) (widely spaced vertical lines), (5) (the German design) and (4) (the narrowly spaced broken vertical lines).

From this whole series of experiments, the investigators draw the following conclusions on configurations to be used in reticle design. (1) Some reticles which differ considerably in configurational aspects do not give great differences in precision of stereoscopic setting for fixed targets and without tracking errors. (2) Long-line reticles seem to be slightly preferable to short-line reticles. Length does not seem to be a variable of first-order significance but, nevertheless, the evidence indicates that long lines lead to slightly better precisions than short lines. Vertical lines are preferable to horizontal lines. Probably the choice of long line will be strengthened as tracking errors are introduced. (3) The results do not justify the hypothesis that a peripheral mass in the fiducial field enhances the precision of stereoscopic setting. (4) When vertical lines are used in the reticle pattern, their separations must be great enough to exclude the possibility that unpaired lines in the two eyes may be fused, hence placing the fiducial plane at the wrong place in space.

Two additional experiments with fixed targets are described in another Brown University report. (173) The first experiment compares the effects, on precision of stereoscopic setting, of two reticle patterns: the Navy open diamond and a so-called "three-dot" pattern. This latter consists of three small dots arranged in a triangle with the dimensions slightly smaller than those of one of the Navy diamonds. The three dots are arranged in a triangle whose base appears to the observer's right with the vertex to his left. The dot at the vertex appears closer by 2.5 UOE than the dots at the base. The task of the observers is to obtain stereoscopic contact of an airplane target between the single nearer dot and the more remote pair of dots. Five observers were used. It was found that the precisions for the two reticles were not reliably different, being 9.3 seconds for the Navy open diamond and 10.2 for the three-dot pattern. These differences are not significant at the 5 per cent level. A second experiment compares precisions with a single Navy open diamond and the three-dot pattern. The precision obtained for the three-dot pattern was 10 seconds and for the single diamond 7.4 seconds. These differences are not significant at the 5 per cent level.

Stereoscopic Movement and Tracking Error

The next several experiments are based upon observations made with both stereoscopic movement and tracking errors introduced. The first of these dynamic experiments contrasts the observations on standard Service reticles or on such reticles modified to a certain extent. (171) Six reticles were used of which four were of standard pattern: (1) Army; (2) Navy line; (3) Navy solid diamond and (4) Navy open diamond. The other two were modified Army reticles as follows: (5) Army without nearest and farthest fore and aft marks and (6) Army with all fore and aft marks removed. Settings were made by ten well trained observers. Settings were made at timed 10-second intervals on a moving airplane target undergoing slow changes in depth and exhibiting

tracking errors. The experiment was so designed that the ten observers viewed the reticles in different balanced order sequences.

The mean values of precision, expressed in UOE were found to be, in rank order: Navy solid diamond: 4.17; Navy line: 4.23; Navy open diamond: 4.26; Army without extreme fore and aft marks: 4.39; standard Army: 4.41; and Army without any fore and aft marks: 4.44. In this experiment, involving a target which exhibits changes in range and tracking errors, the factor of reticle design makes a very slight and statistically insignificant contribution to the variances of all precision values. Variances due to observers are significant at the 1 per cent level, while variance due to days is not significant at the 5 per cent level. Thus, the reticle patterns used seemed to have little influence on precision of setting. The same general finding applies to the accuracy of the settings. For accuracy, variance due to reticles and days is negligible, while variance due to observers is significant below the 1 per cent level. Hence one may conclude that of the six reticle patterns examined, no pattern gives significantly more accurate or more precise settings than any other pattern.

Comparison of Reticle Patterns

In another memorandum is reported an extensive experiment by the Brown University group in the dynamic situation. (176) The first series of observations is concerned with an analysis of precisions of stereoscopic settings made by ten well-trained observers on 17 reticle patterns. Conditions involved a random course of stereoscopic movement plus tracking errors. The subject could control height of image by a fine height adjustment knob. The reticle patterns are described and figured in the text. Many of the patterns are those previously described above in the present summary. The 17 reticles used differ in regard to such aspects as number of lines, size of central gap, anchoring or lack of anchoring of the lines to the circumference of the visual field, presence or absence of a peripheral mass and other details. The experiment was designed so that the ten observers viewed the reticles in a balanced order.

It was found that the five reticles yielding the best precisions in this series are as follows in rank order: the captured German reticle from the R40 – 3.39 UOE; a single vertical line with a 1.8 degree gap in the center of the field—3.43; two banks of short lines with a 0.9 degree gap—3.55; seven vertical lines with a 1.8 degree gap—3.57; seven vertical lines with a 3.6 degree gap—3.61 UOE. None of these reticle patterns had any fore and aft marks. An analysis of variance performed on all 17 reticles shows that reticle differences are not significant at the 5 per cent level. Analysis of variance on the seven-line reticles anchored to the circumference of the field also indicates that differences due to size of gap are not significant at the 5 per cent level. This involves comparison of five patterns with no gap (full-line) and gaps of 0.9, 1.8, 3.6, and 7.2 degree. Similar results were obtained with the single vertical-line group of reticles and the unanchored seven-line reticles when imperfect control of height of target image was present for the largest gaps. A control experiment, with perfected height adjustment indicates, for the seven-line anchored reticle, that precision of performance for the 7.2 degree gap is not significantly different from precision for the 1.8 degree gap.

Analysis thus indicates that, so far as precision is concerned, there is little to choose between a seven-vertical-line reticle and a single vertical-line reticle with the mean position of tracking errors in the center of the field. With off-center tracking errors, the seven-line reticle, in providing more points of reference, should undoubtedly give better precisions because of less separation between the target and a fiducial line.

It was found that the presence of large peripheral masses at the edge of the field does not improve precision over what may be obtained without a peripheral mass—3.83 and 3.63 UOE respectively. The German R40 reticle ranked high in precision. However, it was insignificantly better, statistically, than most of the other reticles. Anchoring of reticle lines to the boundaries of the visual field has no advantage over short lines which are not anchored and, indeed, the values for these two classes are identical at 3.72 UOE each. Finally the correlation between observers' preference ratings for reticles and precision of performance was low ($r = 0.32$).

In a second series of experiments described in this report, nine reticle patterns were used in an attempt to answer three questions: (1) Does thickness of reticle lines have an influence on stereoscopic performance? (2) How good is the German R40 reticle and do modifications influence its goodness? (3) Are circle reticles satisfactory? To answer these questions nine reticle patterns were constructed: (1) Seven-line reticle with thin lines of 1.85′ width; (2) Same reticle

with lines thickened by a factor of 5.0 to 9.25′ width; (3) Navy line reticle (at 14x) with no fore and aft marks; (4) Same reticle but with center post thickened by a factor of 5; (5) German R40 reticle with one set of fore and aft marks; (6) Navy open diamond reticle (at 14x) with nearest sets of fore and aft marks only; (7) German R40 reticle standard with no fore and aft marks; (8) Outline circle reticle and (9) Gray circle reticle with density of circle about 35 per cent.

Twelve subjects were used in this experiment and analyses were made with respect to precision, accuracy, and subject-to-subject consistency. The viewing conditions involved a random course stereoscopic movement and tracking errors. Five height of target image adjustments were under control of the observers.

The results indicate that thickness of line does not seem to contribute reliably to either precision variance or accuracy variance. The thick line reticles give better subject-to-subject consistency than the thin line reticles. The R40 German reticle, with or without fore and aft marks, is not superior with respect to precision to the Navy open diamond reticle, with or without fore and aft marks. For accuracy, the German reticle, with one set of fore and aft marks, is superior to the Navy diamond reticle, with one set of fore and aft marks. The enemy reticle with fore and aft marks is superior to itself without fore and aft marks in respect to accuracy. It also gives excellent subject-to-subject consistency. Finally, the circle reticles, both circle and disc, are unsatisfactory. They give poor precision, high constant errors, and low subject-to-subject consistency. They are extremely susceptible to height-break errors.

16.2.4 Problems of Reticle Design

Loss of Contact with Reticle

A number of special studies were performed at Brown University dealing with specific problems of reticle design. The first of these reported an experiment to determine the ability of stereoscopic observers to signal loss of contact of a target with the reticle in a dynamic situation. (175) This is essentially the situation of aided ranging on a dive target. It is of considerable interest to learn something of the limits of response made by a stereoscopic observer to an accelerating change from stereoscopic contact to a condition where the target appears in front of or behind the reticle. For example, let it be assumed that a device is available for aided ranging. So long as the device exactly compensates for the change in disparities produced by the target, the target will appear to be in stereoscopic contact with the reticle. However, when the device does not properly predict the rate of change of disparity, the target will appear to move away from the reticle at a rate which will be determined by the speed and range of the target. The problem is particularly important in the case of approaching diving targets, where, when the aiding device does not compensate for the rate of change of disparity, the target will appear to emerge in front of the reticle. It is conceivable, in the latter circumstance, that range finder operators might perform some operation which would change the aiding rate and thereby improve the firing data. The feasibility of such operations depends on many factors, among which is the sensitivity of the operator to loss of contact with the reticle. If sensitivity to loss of contact is poor, then it would seem that this fact would set important limitations to the type of operations for which the instruments could be used.

With these considerations in mind, the Brown University group made observations on the just perceptible parallax difference for loss of stereoscopic contact and, in particular, for a condition where the target is emerging from contact with the reticle in an accelerated manner. It will be recognized that these are indeed most exacting conditions of observation.

The experiment was performed on the Eastman Trainer and simulated an airplane diving at the rate of 200 mph from 3,000 to 1,000 meters. At the moment when the observer saw the plane at a range different from that of the reticle he pressed a button on the fine height adjustment knob which was connected electrically to a recording pencil. Thirteen subjects were used and all were practiced in conventional ranging methods but were not skilled in reacting to loss of contact. The results indicate that the just noticeable difference in parallax angle, under these conditions, is both very large and variable. The investigators believe, on the basis of this result, that a method which would involve a correction to true range, based on the observers' response to a rapid deviation from stereoscopic contact, would be unsatisfactory. Such corrections, made for dive conditions, would occur with routine errors of the

order of about 10 to 30 UOE. The duration of the reaction times during which the target is advancing to these values from loss of contact with the reticle vary from about 2 to 8 seconds depending on the rate of range change of the target. Reaction time is fairly rapid for short ranges and slow for long ranges.

Absence of Fine Elevation Adjustment

A second Brown University report on a special problem is concerned with stereoscopic performance of different reticles in the absence of fine elevation adjustments. (177) All previous experiments had been performed under conditions allowing the observers to use the fine elevation adjustment. Since some Service instruments are not equipped with a fine elevation adjustment system, it seemed worth while to compare a sample of reticles, previously compared under other conditions, in the situation duplicating what would be encountered in a range finder with no fine elevation system. Presumably the fact that observers would then be unable to control tracking errors of elevation would introduce poorer precision values, because the target would deviate considerably from the reticle marks. This consideration would be especially pertinent if the reticle were of the Navy diamond or line variety. However, if vertical lines were used which ran across the whole reticle field, it might be possible that the lack of fine elevation adjustment would not interfere with high precision.

To test this hypothesis, four different reticle patterns were compared for precision under these conditions. They were: (1) standard Navy diamond; (2) seven vertical full lines; (3) seven vertical lines with a central gap of 1.8 degrees; and (4) a similar full-line reticle with a gap of 7.2 degrees. The full-line reticle gave the highest precisions while the Navy diamond and the vertical lines with the largest gap gave the poorest precisions. The values in UOE are: full-line reticle–2.71; line with 1.8 degree gap–8.83; Navy diamond–3.29; and line with 7.2 degree gap–3.37. A dynamic course with random change of stereoscopic distance and random tracking errors was used throughout. However, the differences among reticles are not statistically reliable. A comparison of precisions for the Navy diamond reticle under conditions of fine elevation adjustment or no adjustment yielded a statistically unreliable superiority for the condition when the elevation adjustment was present–the values being 3.34 and 3.65 UOE.

False Fusion

Another special problem on false fusion in various reticle patterns is reported by Brown University. (178) Theoretically it is possible for a stereoscopic observer, under certain conditions, to establish contact between a target and a reticle at more than one reading on the range scale. This situation may develop when, by "horizontal slip" on the part of the observers' eyes, unpaired vertical lines of the reticle fuse to produce a reference range different from the true one. Theoretically several false ranges may be established for reticles having lines of the central row too close together. Several reticles were devised to demonstrate this phenomenon. All consisted of parallel vertical lines with a break in the center of the field. The patterns were (1) seven such broken vertical lines; (2) similar but with 11 parallel lines; (3) similar but with 21 parallel lines close together; (4) similar with 21 lines but with five small open circles above and below the break on appropriately paired lines; (5) similar to reticle (4) but with black instead of open circles.

The results indicate that observers may make settings which are quite in line with theoretical expectations derived from a consideration of amounts of slip associated with distances between adjacent fiducial marks of a reticle. Such slip may occur even when adjacent unpaired reticle lines have dissimilar but not incompatible configurations, as in the case of the last two reticles. In certain cases observers give readings indicative of 1 degree of slip, or fusion of adjacent unpaired lines, and at other times, readings indicative of fusion of unpaired lines separated by two intervals. How serious such a situation might be in the field is shown, for example, for the Army Height Finder which has a lateral separation between adjacent lines in the reticle of 60 mils of apparent field at 24x. False fusion or horizontal slip of 1 degree would here produce a range error equivalent to 1.014 UOE, if one assumes that one is dealing with a 4-meter range finder at 24 power and with a target at a range of 10,000 meters and with the range scale reading 10,000 meters. The convergence angle for these conditions is 164.8 UOE. It would be possible, with horizontal slip to fuse unpaired posts of the reticle so that, by moving the range knob, stereoscopic contact could be established for the same target at a new value of convergence angle of 1,178.8 UOE (1,014 + 164.8). Under these conditions and for the

same target, the range scale would read 1,400 meters. It is probable that because of the great difference in range involved and the fact that the fore and aft marks would not be fused for the 1,400-meter range, a confusing situation of this sort would not normally exist in Service instruments. Nevertheless, consideration should be given to this possible source of error in reticle design, particularly as it applies to reticles lacking fore and aft marks, as in the case of full line reticles or their modifications. Reticles with lines closely spaced in the central row provide the greatest opportunities for establishing successive reference planes as a result of increased horizontal slip. Hence no reticle should have central lines which are too closely spaced. Such false fusion can be largely avoided by the use of characteristic identifying marks on paired lines. Finally, the presence of fore and aft marks may avoid false fusion because only a fusion condition can lead to the proper appearance of the entire reticle field.

Height Adjustment Errors

An important report from Brown University deals with the effect of height of image adjustment errors for different reticles. (179) The first experiment in this series deals with the effects on stereoscopic performance of differences in elevation of the two visual fields under conditions where corresponding elements in the two fields maintain constant relative positions. The left field is elevated or depressed through various degrees of angular movement and the subject makes stereoscopic settings for a target which exhibits stereoscopic movement and tracking errors. Precisions and constant errors of subject performance were analyzed as a function of the differences in elevation existing between the two visual fields. The results for seven trained observers using the Army reticle demonstrate the movements—up to $\pm$ 3 mils—of the left visual field with respect to the right field do not result in poor ranging performance, providing no changes in the relative positions of corresponding elements in the fields occur. In these experiments antiaircraft targets and a simulated sky background were employed.

The situation is quite different if there is target height break or poor height adjustment of the target images themselves. A preliminary experiment was performed with 13 observers and 11 reticle patterns and a more extended experiment using 8 trained observers and 8 reticle patterns. Errors of height adjustment of target image of 0, 0.75 and 2.0 mils were used. The results indicate that, for height of adjustment errors in excess of those encountered in an instrument adequately adjusted by trained personnel, reticles which present more complex figures such as diamonds, fore and aft marks do not increase or decrease the effectiveness of performance in the presence of height adjustment errors. For example, the Navy diamond reticles were most affected by a 2-mil height break error and a single vertical line was least affected. An analysis of variance performed for the 2-mil error indicates that, at this separation of images, variance due to reticles is significant at the 1 per cent level while observer variance is significant below this level. This result may be understood if one considers that misalignment of the target images leads to the introduction of varying disparities in the eyes when a given fiducial mark is of such shape that the horizontal distance between target and fiducial mark changes when the target is moved vertically with respect to the fiducial mark, as in the case of the diamond.

Thickness of Reticle Design

Brown University, having determined the importance of height of image adjustment errors (see 179) reported elsewhere in this summary, did a further experiment on this problem using four reticle patterns. (182) These consisted of (1) the Navy closed diamond without fore and aft marks; (2) three widely spaced vertical lines; (3) five evenly spaced vertical lines; and (4) five vertical lines unevenly spaced. The last is a new pattern not tried before in the Brown experiments. It was designed to minimize the possibility of false fusion without providing fore and aft marks because it is impossible for an observer to fuse unpaired lines on the two eyes without observing either a doubling of the number of reticle lines or a view of a reticle in which fiducial lines appear in different depth positions. The results of the present experiment are in harmony with those of the previously reported results in showing that height of adjustment errors have influence on stereoscopic performance only when the errors are extreme and at least greater than 1 mil. Of the four reticles tried, the Navy diamond gives the poorest performance for the largest height break of 2 mils. The long vertical-line reticles are not so susceptible to height of image break. Although these tendencies are clear cut, none of the differences are statistically significant.

Brown University presents an experiment concerned with an analysis of the performance of stereoscopic observers when observations are made on a stationary target parts of which are obscured by reticle lines of various thicknesses. (181) A series of preliminary experiments demonstrated that, when thick reticle lines obscure parts of the target, observers tend to develop unwanted, complex forms of ranging performance. Ranging under these conditions involves use of lateral movement and coincidence cues. When, in the final experiment dependence on unwanted cues was minimized by a procedure which did not allow for bracketing, performance with thick-line reticles, which obscured large parts of the target, was poorer than performance with thin-line reticles. In these final experiments nine trained observers used single vertical full-line reticles 4 minutes 3 seconds and 1 degree 22 minutes in width. The target subtended an angle of 5 degrees 8 minutes. The average standard deviations of settings with the thick-line was 9.44 UOE and with the thin line 1.94 UOE. These differences are statistically reliable.

Torsion of Eyeballs

Another phase of reticle design, investigated at Brown University, was the possible effects of torsion of the eyeballs. (183) Torsion, the rotation of the eyeballs about their sagittal or antero-posterior axes, is a phenomenon which occurs in all persons, with or without known eye defects. It occurs presumably because the external eye muscles have their posterior attachments nasal to rather than directly behind the eyeball. Such torsion increases with increase in the degree of convergence and with increase in elevation.

Consideration of the range finder situation leads to the belief that very little torsion occurs in viewing the visual field of the instrument. Nevertheless, it seemed worth while to examine the possibility that torsion might influence stereoscopic settings because: (1) Long, vertical reticle lines might show a slightly greater separation of the images in the two eyes at the tops of the lines than at the bottoms. Thus the tops of the reticle lines might seem further away than the bottoms. (2) Targets seen below the reticle might seem slightly nearer than targets seen above the reticle. (3) Since torsion may be overcome by the provision of strong fusional stimuli, observations made with "peripheral masses" in the visual field would be expected to show diminished torsion effects, if such should occur.

In the experiments, no significant effects on stereoscopic settings could be traced to the presence or absence of peripheral masses and these are believed unnecessary. The results did indicate that there are great individual differences in the differences between above reticle and below reticle settings. Of the eight observers tested, very few show comparable readings for the above and below conditions. Most of the subjects gave greater range settings when the target was below the target but the reverse tendency appears with the remainder.

Brown University reports still another experiment testing a five-vertical-line reticle with respect to resistance to height break. (184) This reticle was presented in its simplest form and in modifications involving presence or absence of fore and aft marks or of a horizontal line which was placed below the fiducial marks. The results show that the vertical line reticle shows high resistance to height break and also it is possible to add fore and aft marks and/or a horizontal line to the reticle without detriment to observer performance.

In another section of this report is discussed the question of precision and accuracy of height of image adjustment for the two reticle patterns with fore and aft mark and with and without the horizonal line. Two types of target were used—a poor target with fuzzy edges and the clear airplane target used in previous experiments. Both monocular and binocular methods of adjustment were employed. No differences were found between the two methods. So far as single settings are concerned, it was found that 90 per cent of the individual readings of all subjects with the poor target fall within a spread of 1 mil from zero error (defined as the average for the monocular series). With tracking errors introduced in the poor target and with the binocular method, which is a condition which gives poorest precisions, 77 per cent of the individual readings of all subjects fall within 1 mil of the zero error setting given by the monocular method. Higher percentages of readings fell within the 1 mil limit for all other conditions. Finally, it was found that the introduction of a short horizontal line into the reticle pattern does not add appreciably to the precision of making height adjustments.

All of these Brown University reports on opaque reticle patterns are summarized in a final report. (186) The authors are led to believe, from their experiments, that the most important considerations

with regard to reticle design center about the problems of height of adjustment errors and false fusion, i.e., the fusion by the observer of unpaired reticle lines.

Conclusions

In regard to the height of adjustment errors, it seems safe to conclude that vertical line reticle configurations provide better insurance than do others against poor performance when the height of target above or below the reticle is unequal in the two eyes. For height of adjustment errors either in excess of those encountered in an Army instrument adequately adjusted by trained personnel (±0.5 mil of apparent field) or probably within conventional errors exhibited by Navy personnel under conditions which routinely involve difficult conditions of ranging, reticles which present simple vertical line fiducial marks are superior to those which present more complex figures, such as diamonds. The vertical lines of the reticle should be sufficiently long, of 5′ of true field. The vertical lines should not be so thick as to obscure large parts of stationary targets and 0.20′ of true field is recommended.

The question of false fusion is important to reticle design because, unless a reticle is so designed that fusion of unpaired reticle lines is made impossible, an observer might in certain instances establish contact between a target and a reticle at more than one reading of the range scale. For reticles without fore and aft marks it would be necessary to calculate a proper spacing for vertical marks of the central line so that false fusion may be eliminated. Under certain circumstances, this procedure may lead to a very few widely spaced lines at high magnifications. For this reason, it may be desirable, in some reticles, to include a minimum number of fore and aft marks. Another type of reticle, one with varying interline spaces, may also be used to eliminate the possibility of false fusion. It is the experience of the investigators that the presence or absence of fore and aft marks of the conventional design has little effect on stereoscopic performance. Their presence eliminates the possibility of false fusion but a minimum of such marks is all that is required. The report recommends that there should not be more than a single pair each of fore and aft marks and that 25 to 50 UOE may be reasonably recommended as a satisfactory spatial separation in depth from the central line.

The report contains recommendations for the pattern of a Service stereoscopic reticle previously reported to the Navy Bureau of Ordnance at their request. (185) This consists of five vertical fiducial lines, with one pair each of fore and aft marks, all of a size and in an arrangement which best takes into account the configurational principles derived from the experiments.

This final report from Brown University including 19 Memoranda reporting individual experiments, all of which have been summarized above, is attached as supporting data to a Report to the Services issued by the Fire Control Division of NDRC. (44) This report recommends Service trials of the reticle design suggested by the Brown University personnel.

16.3 STADIOMETRIC RANGING

The following reports from the Foxboro Company are discussed at this point mainly for the sake of completeness because the work was done under the direction of the NDRC Fire Control Division, and also because the material is of considerable interest. These experiments dealt with different patterns of reticles for stadiometric ranging and of different reticle patterns of sights rather than optical range finders of the more conventional sorts.

The first Foxboro report retails comparative tests of three stadia ranging reticles with ring, dots and disc patterns. (218) Tests were taken under field conditions with actual airplane targets and with high angular velocities. A photographic technique of recording was employed. Tracking was done with handle bar controls and ranging with a double foot pedal. Acting as observers were 13 Naval personnel and one civilian, none of them had previously had training with handle bar control or those types of sights for simultaneous tracking and ranging. The results indicate that there are no significant differences between these three patterns so far as ranging accuracy is concerned but that the ring is definitely inferior to dots or disc in tracking accuracy.

An examination of the records indicates that the task of ranging and tracking simultaneously is difficult for inexperienced operators who tend to concentrate now on one, now on the other aspect during the test. Both variability from test to test and the ratio of poorest to best operators are greater in ranging than in tracking. No evidence of improvement was found during the tests due to the limited amount of practice afforded. In these tests the majority of op-

erators tended to range short, that is, to make the diameter of the reticle larger than the largest dimension of the target. Less than 10 per cent of all measured photographic frames showed the opposite tendency. Largest ranging errors were found with the large reticles or shorter ranges, both because of the increasing rate of change in target velocity and because of greater difficulty in matching the larger extents visually.

Although the tests were made primarily to obtain stadia ranging data, information regarding types of tracking errors was obtained from viewing the films of the tests as well as from measurement of the individual frames. With the ring reticle the tendency is to center the target in the upper half of the circle, while with the disc the tendency is to center the lower half. With the dot pattern, which was the only configuration having a center dot, there was a tendency to center the target in the upper half but the elevation errors were much smaller and the total time off target was much less than with the other two patterns.

The errors in the first study were so large for inexperienced personnel that the Foxboro Company set up a laboratory experiment to determine the feasibility of training a man to operate simultaneously the triple controls for simultaneously following a target in azimuth, elevation, and range. (221) Handle bar controls were used for tracking. Two devices were compared for the foot ranging—the standard opposed action pedal mechanism for the two feet and also a horizontal lever vertically pivoted in the center to be pressed by the two feet. Only the hexagon dot pattern with the central dot was used.

The results with both the cross-bar and opposed-pedal forms of foot control demonstrate that under favorable conditions in two or three hours considerable proficiency is possible in simultaneous hand and foot functions. All operators participating were successful in developing this coordination. However, the simultaneous functioning reduces the accuracy of separate manual and pedal functioning. Even under favorable conditions, 10 hours of practice amounting to 100 runs may be required to compensate the added difficulty of the triple performance. A training schedule seems important in this respect as evidenced by the result of three groups trained differently — simultaneous tracking and ranging, tracking first and ranging added, and ranging practice first and tracking added. More accurate simultaneous functioning followed 4 hours preliminary practice in a single function than 4 hours in the simultaneous functions. Under such conditions, 5 or 6 hours of the latter were sufficient to compensate for the added difficulty.

During the simultaneous performance, greater improvement was in the ranging when the initial training was only in ranging; it was in the tracking when the initial training was only in tracking. A significantly greater advantage was secured when the operators were first trained to track alone before ranging was added, presumably because of the significantly greater difficulty of the tracking operation. The ranging scores with the cross-bar and with the opposed-pedal controls did not differ in accuracy. The pedals may be rated slightly higher on three counts; less foot slippage, slightly better score, and unanimous operator preference. Foot controls of the sort investigated are open to criticism because the coordinations might break down under strain or distraction and because the feet are often needed to support or brace the body during manipulations of hand controls.

Chapter 17

NEW INSTRUMENTS

As a result of development during this period and as a result of some of the experiments discussed above, new instruments have been or are being developed in which it is hoped to eliminate or at least better control some of the sources of error found in the present standard Service range finders. Part of this development has been the production of better and thermally more stable instrument parts already referred to in Section 5.4 above in this report.

17.1 USE OF RHODIUM COATING

Additional suggestions for the development of better instrument parts are found in two reports by the British Admiralty Scientific Research Department. The first of these describes the methods of manufacture employed by Adam Hilger, Ltd. for the production of plane parallel glasses to be used as mirrors in range finders. (59) It also discusses the making of rhodiumized windows for use in setting the infinity mark of range finders on the sun. Rhodium is used for this purpose since it does not tarnish or corrode in sea air, although its reflecting power is considerably less than that of freshly deposited aluminum. The official British specifications are given. The second report discusses the special difficulties encountered in the rhodiumizing routine and shows how these difficulties have been overcome. (60) In recent years, the use of rhodium has gained great importance as a material for making surface reflectors and semi-transparent filters. Four properties of the rhodium films render this metal particularly suitable for these purposes: (1) high reflectivity, (2) neutral color in transmission, (3) hardness, and (4) resistance to chemical attacks. The report closes with a detailed description of the evaporation method of depositing this metal on glass surfaces. Many precautions in the use of this technique are given.

17.2 BASIC REQUIREMENTS OF RANGE FINDERS

Several theoretical studies regarding the basic requirements for satisfactory range finders and range finder operation have been reported by the Princeton Branch of the Frankford Arsenal. The first of these discusses the basic physical and physiological requirements of a satisfactory instrument. (231) Because they crystallize the picture of range finder adequacy, it seems worth while to give the suggested requirements in detail, although some readers will not agree with all of the items as stated.

1. The range finder shall have a standard path not subject to appreciable error.
2. The working path of the range finder shall be the same as the standard path, shall be continuously compared with the standard path, or shall not be subject to appreciable change during one hour.
3. Using a target at fixed range, temperature changes and other service conditions shall not cause more than 0.1 diopter of unbalanced focus difference between target image and reticle image.
4. The difference in focus of target image and reticle image at a target range of 10,000 yards, a long tactical range, shall be less than 0.05 diopters.
5. The spherical aberration of each image shall be less than 0.05 diopters.
6. It shall be possible to adjust the interocular distance (the distance between the centers of exit pupils) with an accuracy of 0.1 millimeter and the setting shall maintain this accuracy for 1 hour.
7. Exit pupils of 1 and at least 4 millimeters shall be provided.
8. The product of the base length and the magnification shall be at least 324 feet.
9. The loss of light in the range finder shall be not more than 35 per cent.
10. Throughout the optical system, the glass surfaces shall be coated to decrease reflection.
11. The errors involved in data transmission shall correspond to triangulation errors of less than 0.5 seconds of arc at all slant ranges greater than 2,000 yards and to errors corresponding to slant range errors of less than 2 yards at shorter ranges.
12. The angle between the directions of the optic axes of the oculars shall be less than 10 minutes.
13. The reticles shall have been shown to be at least as good as current Service patterns by a satisfactory testing procedure.
14. It shall be possible to make a height adjust-

ment to within 10 seconds of the true adjustment.

15. The range finder shall be provided with filters which have been shown by adequate tests to give as good range finder performance as those now used by the Services.

16. The required rate of range-knob rotation, averaged over tactical situations weighed according to their importance, shall not be more than four times as large as the least average obtainable by a combination of range-height conversion mechanisms and regenerative range. The reasons for the choice of these specifications are discussed in the text of the report.

The second report by the Princeton Branch of the Frankford Arsenal report discusses a program of basic experiments of importance on range finder redesign. (233) The emphasis is upon physiological experiments on the potential observer and on data transmission to the director rather than upon experiments entirely on instrumentation of the range finder itself. Information is desired on such problems as the acuity of a normal or of slightly annetropic observers, reticle design, and effect of increased power on acuity under poor seeing conditions as well as on data transmission problems.

The Frankford Arsenal Princeton Branch reports a proposed program of study and design of a unified field modification of the M1 Height Finder. (247) The report includes a discussion of the principal problems which, as far as is known to date, must be solved in order that the performance of this instrument may be suitably improved. It also discusses in considerable detail the various devices, modifications, and attachments which were then (1943) under consideration for design, construction, and testing in an effort to solve these problems in a practical manner. Another report from the same group outlines suggested modifications to be made in a special M1 instrument for experimental purposes. (237) It is suggested that, in order to control perspective error, focusable objectives, special reticles, modified interpupillary scale and adjustment, diopter scales, controlled apertures, and height adjustment be introduced. To control stratification, modifications are suggested for the temperature tubes, introduction of Pyrex end reflectors of new design, internal-adjuster collimating reticles, and also changed penta-prism mounts are to be introduced to control problems of mechanical deformation. Other problems such as differential aberration, fungus growth, modified range drum, and coated optics are briefly discussed.

In a final report on this topic by the Princeton Branch of the Frankford Arsenal, the results are of the integrated program of modification. (258) A long list of modifications already standardized, some designed to reduce or eliminate errors or mechanical difficulties in operation are given and discussed.

17.3 SUGGESTED IMPROVEMENTS

Until now in this section of the present report, there has been discussed modifications or changes in the existing range finders. Below will be given a discussion of instruments which involve new approaches to the problem of obtaining range, or novel approaches to the elimination or control of some of the more important sources of error.

A captured German 4-meter range finder, Model Em 4 m R 40, was studied by the Fire Control Design Division of the Frankford Arsenal. (228) This is a stereoscopic instrument capable of reading ranges from 1,200 to 100,000 meters. Ortho-stereoscopic and pseudo-stereoscopic fields can be selected at either 20 or 32 power. It has coated optics throughout. The range finder proper, the outside of which is a one-piece aluminum alloy casting except for end boxes, bearings, and auxiliary plates, rests on a cradle containing elevation and azimuth hand wheels and mechanisms. This in turn rests upon a tripod, which is leveled by two horizontal screws, 90 degrees apart.

Little insulation was found on the range finder proper, although metal sunshades extend on both sides from the main bearing housings to the end boxes. The interior of the end boxes is insulated by sheets of some aluminum alloy. The instrument has no inner tube, and has an optical bar only for reticle collimation. Fixtures for optical elements and internal mechanisms are positioned on the inside of the casting by machining a surface where attachment is desired and then hand-lapping the fixture into place.

Because the elevation scale goes from 0 to 90 degrees, it is believed that the instrument is an antiaircraft range finder, although the only range-to-height device is a conversion table on the right end box. It is thought that the range finder proper can also be placed on an antiaircraft director, into which it would then feed slant range, by means of a clutch device which is connected directly to the range knob mechanism. The instrument was made by Zeiss. The controls, main optical path, optical path of reticles,

daylight and artificial illumination of reticles is described. A collimator, as a separate instrument, was captured with this range finder.

The same instrument and the collimator are also described by the Aberdeen Proving Ground. (45) Brief descriptions of operational procedures, photographs and schematics of the range finder and its collimator are given. The important new aspect of this instrument is the elimination of the optical bar in its construction and the attachment of the optical parts directly to the main tube. The reticles of this instrument are new and have been discussed above in the section on reticle design. The comparative tests of this instrument by the Aberdeen Proving Ground (46) are also discussed above in the section on comparison of instrument types.

An instrument of ortho-pseudo stereoscopic type was developed by the Eastman Kodak Company and is described in detail in a report published by them. (204) This instrumental design eliminates reticles and hence elminates all parallax errors provided the right and left hand telescopic systems are accurately matched. The field of this instrument shows two images of the target in the upper and lower halves of the field. These may be varied in stereoscopic distance and the problem of the operator is to bring the two images into the same stereoscopic plane. A limitation of this present design is that a standard M1 Height Finder was modified for this purpose "with the fewest possible changes" which decidedly limited the development possibilities for the designers. It was hoped that this instrument would give better results under poor seeing conditions. In this case the ortho-pseudo field would present two images of similar brightness and background contrast for comparison instead, as in the case of reticle type stereoscopic instruments, of target and reticle images of different brightness and different background contrasts. An ortho-pseudo instrument presents the difficulty in adjusting the two stereoscopic images to allow for increasing size as range decreased and in maintaining, by exceptionally good tracking, the two images near the halving line.

Results of comparative tests of the Eastman ortho-pseudo range finder and standard Army height finders have already been described above and appear in a report from the Princeton Laboratory at Fort Monroe. (351) These two reports are attached as supporting data to a Report to the Services issued by the Fire Control Division of NDRC. (21) This report summarizes these results as follows. When all the available information is taken into account, there appears to be good reason to believe that a well designed ortho-pseudoscopic range finder in the hands of a well-trained crew would be more accurate, and more consistently accurate, than any other instrument so far devised. A similar amount of turn of the range knob should give twice the amount of movement between images in the ortho-pseudo situation as in the reticle type of instrument. The report further states that, in time of peace, or if procurement of optical range finders were not so difficult, an energetic prosecution of this development would obviously be warranted.

The Princeton Branch of the Frankford Arsenal suggests the design of optical range finders employing polarizing beam splitting surfaces to combine all of the target beams to be presented to an observer. (248) In this report, a number of schemes for arranging the polarizing surfaces to combine target beams in the desired fashion are presented together with various methods for obtaining the common types of field presentation — reticle stereoscopic, erect split field coincidence, and invert ortho-pseudo. A discussion of the general optical characteristics is given and the conclusion is drawn from this discussion that the special features possessed by this type of range finder are such that it would be a good, versatile instrument which would be relatively simple to construct and maintain. It is believed that the chief application of this principle would be as a short-base high-power instrument under conditions where two observers sharing the same range standard and using different viewing instruments can be utilized to advantage. At the time of the publication of this report (February 1944) there appeared to be considerable difference of opinion as to whether the art of polarizing beam splitting had reached a degree of excellence sufficient for this application. Another report from the same source considers the application of this polarizing beam splitting type of range finder for tank use and considers the advantages and disadvantages attendant upon such application. (252)

In this connection, the Eastman Kodak Company subsequently published a description of work on a polarizing beam-splitter by evaporating alternate films of high and low index materials on glass. (214) The report discusses the principles of such a device and the methods and difficulties of manufacture.

Although these experiments have demonstrated that it is possible to make a polarizing beam splitter with characteristics almost the same as those predicted by theory, the Eastman Kodak group point out three primary limitations to this type of prism. (1) Although the transmitted beam is efficiently polarized over a wide angle, the reflected beam is limited to a narrow angle of about 2 to 3 degrees. (2) The prism is effective for a limited band of wave lengths, slightly less than the width of the visible spectrum. (3) Very careful control is necessary to make satisfactory beam splitters inasmuch as the problems encountered in the vacuum evaporation of multiple films are, in general, still formidable.

The Eastman Kodak Company designed and produced almost complete layout drawings for a 13½ foot superimposed type range finder. (212) It was suggested that, with the increased use of radar range finding devices, the optical range finder might become merely a standby instrument. Hence a range finder of the superimposed type would be simpler in operation and less expensive to manufacture than the stereoscopic instrument. The designed instrument was to have 24 x magnification and a field angle of 1½ degrees and was calculated to be effective to 20,000 yards. The instrument is described in the report. After approximately 90 per cent of the detailed drawings had been completed, the project was discontinued.

As a result of the foregoing experiments and the resultant better appreciation of the sources of error in present Service range finders, a meeting was called at the Frankford Arsenal to discuss the feasibility of completely new range finder design on March 15, 1943 under the auspices of NDRC. There were present Army representatives from Ordnance and the Antiaircraft Artillery Command, from the Naval Bureau of Ordnance, and from each of the three principal manufacturers—Bausch and Lomb Optical Company, Eastman Kodak Company, and Keuffel and Esser. The result of this meeting was a second meeting on April 16, 1943 at the University Club in Boston for the discussion of problems. A third meeting was held in Washington, D. C. on September 15, 1943 by which time a Steering Committee for the "Super Range Finder" had been organized including Army and Navy, and NDRC personnel and representatives of the three manufacturers. At this time, the manufacturers presented schemata of types of range finders which they would like to develop. The Steering Committee authorized the design of two different types of instrument by Bausch and Lomb, two by the Eastman Kodak Company and one by Keuffel and Esser. In addition the National Bureau of Standards was working on a new design entirely apart from the NDRC development. Three of these designs were selected as most promising and Bausch and Lomb was requested to design and build two of them and Eastman Kodak Company one. Two instruments of each of these three designs were authorized so that the Army and Navy could run separate simultaneous tests. Various details of design and construction were decided upon. Still another meeting of this group was held in Rochester, New York on July 12 and 13, 1944. At this time progress reports were made by each of the three manufacturers. There was also a demonstration of two "breadboard models" developed by the Eastman Kodak Company. Detailed reports on other matters were presented at this time.

Schemata of these designs are presented in the conference reports referred to above. No details are available at the date of the present report since none of these instruments is as yet entirely completed (October, 1944). Schemata of the designs will be found, for Bausch and Lomb (112, 113) and, for Eastman Kodak Company (197, 200, and 201).

A more detailed description of two forms of the Eastman Kodak Company designs are to be found in a subsequent report. (213) This report also summarizes experiments and developments on component parts of the super range finder.

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418. *Preliminary Study of Trends in H. F. Readings from Data Taken during August and September 1940,* Apr. 1, 1941, p. 10 (14).

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436. *Thermocouple Measurements of Internal Temperatures,* June 1, 1941, p. 6 (5).

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451. *Stratification Tests at Eastman Kodak Plant,* Oct. 24, 1942, p. 8 (5).

452. *Mathematical and Maximum Error Theory of Aerial Photography,* June 1, 1941, p. 47 (14).

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458. *Recommended Methods of Calculation and Theodolite Locations,* Aug. 1, 1941, p. 4 (14).

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463. *Reproducibility of R. F. Determinations with 12 and 24 Power; Fixed Targets,* Aug. 1, 1941, p. 2 (6).

464. *RCS and Power,* Aug. 1, 1941, p. 1 (6).

465. *Net Correction to RCS and Power,* Aug. 1, 1941, p. 1 (6).

466. *Comparison of 12 vs. 24 Power on Aerial Courses* (Very Preliminary), Apr. 18, 1942, p. 5 (6).

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468. *Variation of Height Finder Performance with Type of Filter Used,* Oct. 5, 1942, p. 5 (8).

469. *Ocular Tests and Some Case Histories (Preliminary Report on Experiment* I), July 1, 1941, p. 4 (13).

470. *Psycho-physiological Selection Tests and Two Case Histories (Preliminary Report on Experiments W1, W3, W4, W5),* July 1, 1941, p. 7 (13).

471. *Screening Tests for Class 11,* Nov. 26, 1941, p. 14 (13).

472. *School Performance of Classes 7-10,* Jan. 29, 1942, p. 23 (14).

473. *Prediction of Theory and Records Performance from Pencil and Paper Tests,* Jan. 29, 1942, p. 7 (13).

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486. *Reliability of Interpupillary Distance Measurements,* July 2, 1942, p. 1 (13).

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493. *Visual Acuity and Test Performance, Eustis* II, July 2, 1942, p. 7 (13).

494. *Eustis* III*—Distribution of Stereo Vertical Scores,* July 21, 1942, p. 1 (13).

495. *Comparative Reliability of Fixed and Aerial Trials, M2 Trainer,* July 21, 1942, p. 2 (13).

496. *M2 Trainer Performance and Time Required to See Stereo, Eustis* II, July 21, 1942, p. 2 (13).

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506. *Phoria and Variability of Fixed Target Readings,* Aug. 21, 1942, p. 6 (13).

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530. *A Study of Examiner Differences,* Sept. 14, 1942, p. 6 (13).

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556. *Report,* Feb. 1942 (4) (10).

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565. *Intercorrelations of Scores on the Bott Test of Stereopsis, the Navy Mark* II *Stereo-Trainer and the Tufts Stereo-Trainer,* Leonard Carmichael, Bertram Wellman, and others, Apr. 24, 1942, p. 29 (13). Div. 7-220.15-M1

566. *The Test-Retest Reliability Coefficients of the Tufts Stereo-Trainer, the Navy Stereo-Trainer Mark* II *and the Bott Test of Stereo Acuity,* June 18, 1942, p. 16 (13). Div. 7-220.15-M4

567. *Comparison of Men and Women Subjects on the Tufts Stereo-Trainer, the Navy Stereo-Trainer Mark* II *and the Bott Test of Stereo Acuity,* June 18, 1942, p. 10 (9) (13). Div. 7-220.15-M5

568. *The Correlation Between the Keystone and Bott Tests of Stereopsis and Influence of Size of Test Stimuli in Judgments of Stereopsis,* June 18, 1942, p. 8 (13). Div. 7-220.15-M6

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570. *High Impedance Direct-Reading Vacuum Tube Voltmeter for DC,* July, 1942, p. 14. Div. 7-220.211-M3

571. *The Effect of a Two-Week Layoff After Training on Stereo Performance,* OEMsr-66, July 15, 1942, p. 4 (9). Div. 7-220.17-M2

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575. *Summary Report of Research and Development Work from August 1, 1942 to July 1, 1943,* June 30, 1943, p. 10 (10). Div. 7-220.16-M10

576. *Experiments with British Seamen at Fort Monroe and Providence, October 8-17, 1941,* October 1941, p. 20 (13). Div. 7-220.11-M2

577. *Survey of Experiments Performed at Tufts College,* June 22, 1943, p. 22 (10).

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578. *Comments on Branch Memorandum No. 5,* p. 35 (17).

579. Letter from T. C. Fry to Col. W. R. Gerhardt dated Oct. 7, 1943 (15).

580. *The Application of the Wulfeck Group Test of Stereo Acuity at Randolph and Kelly Fields, May 25 to 30, 1942,* Samuel W. Fernberger, May 1942, p. 14 (13). Div. 7-220.12-M5

581. *A Proposed Group Test of Stereo Acuity,* 1942, p. 11 (13). Div. 7-220.12-M23

582. *Second Report re: Validation of Tests Against the Navy Scoring System, Samuel W. Fernberger,* Oct. 19, 1942, p. 5 (13). Div. 7-220.15-M9

583. *Stereo Acuity Testing on Aviation Pilot Candidates at the Philadelphia Navy Yard.* 1942, p. 9 (13). Div. 7-220.12-M3

584. *The Validation of Tests Against the Navy Marking System,* Samuel W. Fernberger, Sept. 22, 1942, p. 5 (13). Div. 7-220.15-M8

The text of this technical monograph was closed on February 22, 1945. For the sake of completeness, the following section includes several titles dealing with rangefinders and their operation which were received from that date until October 1, 1945. However, summaries of these titles do not appear in the text.

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585. *Influence of Visual Magnification on Accuracy of Tracking,* RS 90, Apr. 1945, p. 3.

586. *Studies in Lead Tracking with Machine Gun Sights,* Division 7, RS 92, OEMsr-453, The Foxboro Company, June 1945, p. 6. Div. 7-220.32-M2

587. *Studies of the Design of Illuminated Reticles for Stereoscopic Range and Height Finders,* RS 93, July 1945, p. 3.
588. *On a Modified Internal Adjuster System for Stereoscopic Rangefinders,* RS 94, Sept. 1945, p. 3.
589. *On the Relation of Atmospheric "Boil" to Magnification and Base Length of Stereoscopic Ranging Instruments,* RS 95, Sept. 1945, p. 3.
590. *Factors Influencing the Magnitude of Range Errors in Free Space and in Telescopic Vision,* Oct. 1945, p. 7. (Included in Ref. 283.)

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591. *Rangefinder, 70 cm base, Stereoscopic (Model IV/a) German (FMFC 367),* Jan. 16, 1945, p. 5.
592. *Rangefinder, 1.5 meter base, Model 96, Japanese (FMFC 372),* Feb. 12, 1945, p. 6.

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593. *Generality of Tracking Training,* Dec. 28, 1944, p. 8.
594. *A Study of Errors of Prediction Resulting from Azimuth Tracking Errors in the Director M7,* Dec. 28, 1944, p. 13.
595. *Manual for the Installation and Adjustment of the Multiple Projection Eikonometer,* Oct. 10, 1944, p. 73.

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596. *The Accuracy of Range Finders in H.E. Shoots,* Jan. 23, 1945, p. 15.

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597. *German Rangefinder Trainer for Use with Em. 4 m. R.H-34 and 36 Rangefinders,* Jan. 24, 1945, p. 4.
598. *The Removal of Elevation Error from the Army Heightfinder No. 3. Type U.B. 7 by Circumferential Air Stirring,* Jan. 25, 1945, p. 12.

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599. *Summary of Research on the Design of Illuminated Reticles,* Clarence H. Graham, Lorrin A. Riggs, and others, OEMsr-1059, June 16, 1945, p. 17. (Included in Ref. 587.) Div. 7-210.31-M10
600. *A Modification of the Internal Adjuster System of the Stereoscopic Range Finder Mark 65, With Comparative Data on the Effects of Temperature on the Modified and the Standard Instruments,* Lorrin A. Riggs, C. G. Mueller, and F. A. Mote, OEMsr-1059, July 21, 1945, p. 9. (Included in Ref. 588). Div. 7-210.112-M5
601. *Photographic Measurements of Atmospheric Boil, with Some Preliminary Theoretical Considerations of the Relation of Boil to Range Finder Magnification and Base Length,* Lorrin A. Riggs, C. G. Mueller, and others, OEMsr-1059, Aug. 6, 1945, p. 13. (Included in Ref. 589.) Div. 7-210-M6

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602. *Influence of Visual Magnification on Accuracy of Tracking* (Memorandum 14), OEMsr-453, Apr. 5, 1945, p. 6. (Included in Ref. 585.) Div. 7-220.312-M2
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